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ESTABLISH MANUFACTURING METHODS FOR CLOSED DIE ALUMINUM FORGINGS WITH IMPROVED STRESS CORROSION RESISTANCE

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Wyman-Gordon

TECHNICAL REPORT AFML-TR-69-264

September 1969

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Air Force Materials Laboratory

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Charles A. Morris
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FOREWORD

This Final Technical Report covers the work performed under Contract AF-33(615)67-C-1040 from 1 October 1966 to 1 September 1969. It is published for information only and does not necessarily represent the recommendations, conclusions or approval of the Air Force.

This contract with Wyman-Gordon Company, Worcester, Massachusetts, was initiated under Manufacturing Methods Project No. 9-126 "Establishment of Closed Die Aluminum Forging Process for Improved Stress Corrosion Properties". It was accomplished under the technical direction of Mr. George W. Trickett (MATB) of The Manufacturing Technology Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

Mr. Charles Morris was Project Engineer and Mr. Anthony G. Cerrone was Experimental Project Engineer, responsible for mechanical design.

This project has been accomplished as part of the Air Force Manufacturing Methods program, the primary objective of which is to implement, on a timely basis, manufacturing processes, techniques, and equipment to use in economical production of USAF materials and components. This program encompasses the following technical areas:

Metallurgy	- Rolling, Forging, Extruding, Casting, Drawing, Powder Metallurgy, Composites.
Chemical	- Propellants, Coatings, Ceramics, Graphites, Nonmetallics.
Electronic	- Solid State, Materials & Special Techniques, Thermionics.
Fabrication	- Forming, Material Removal, Joining, Components

Suggestions concerning additional Manufacturing Methods required on this or other subjects will be appreciated.

This technical report has been reviewed and is approved.

George M. Glenn
G. M. GLENN, Acting Chief
Materials Processing Branch
Manufacturing Technology Division

ABSTRACT

To evaluate SCC susceptibility as it relates to forging processing, a 7079 aluminum alloy landing gear outer cylinder was produced using five different forging techniques. Three of these techniques formed the part with a solid barrel using differing preliminary open die working. The other two techniques involved forward and backward extrusion.

Standard uniaxial-tensile testing revealed no significant difference between the various forging techniques. However, alternate immersion stress corrosion testing in 3 1/2% NaCl indicated differences in stress corrosion cracking susceptibility. The two extruded forgings (forward and back) were significantly more resistant to SCC. The forward extruded parts were somewhat more resistant to SCC than the back extruded parts, but were also substantially more expensive to produce.

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INTRODUCTION

Since the introduction of high strength aluminum zinc magnesium alloy forgings, stress corrosion cracking has been a serious problem. The somewhat unpredictable nature of this cracking (many different and sometimes seemingly innocuous materials can sensitize these alloys) and the low average stress levels at which this cracking can progress, make it particularly difficult to design for this type of failure.

The cracking generally progresses along an intergranular path and follows the grain flow. Because of the elongated grain structure in these alloys, failure by this method is rare when the load is parallel to the grain flow due to the long intergranular path for failure. However, when service loads are in the short transverse direction (perpendicular to the grain flow), failure by stress corrosion cracking is a very real possibility and, due to the relatively short straight intergranular path, these failures can be fairly rapid.

Susceptibility to stress corrosion cracking can often be reduced by overaging these alloys. This method is quite successful and is currently being used quite generally. Nevertheless, one must pay a penalty in reduced strength and structural efficiency when this is done.

Another approach to this problem is to design the forging so that there is no or a minimal amount of grain runout - i.e., grain flow should follow as nearly as possible the finish machine part outline. This then produces a longitudinal grain flow all over the part surface with a long intergranular crack path.

Unfortunately, it is almost impossible except in the simplest of configurations to produce a forging without any end grain. Furthermore, subsequent machining of the forging generally exposes even more end grain. Thus, the problem becomes one of controlling grain flow so that end grain is exposed only in areas which are not critically stressed in service.

SUMMARY

1. Landing gear outer cylinder forgings were produced with improved resistance to stress corrosion cracking by changes in the forging practice and metal movement. In order of increasing resistance to stress corrosion cracking at the barrel bore surface, the methods used were:

   a. Conventional forge, regular cog and upset cog (these three methods had about the same resistance to SCC).

   b. Back extrusion

   c. Forward extrusion.

2. Although the forward extrusion technique produced parts which were somewhat more resistant to SCC than the back extrusion method, forgings produced in this manner were more expensive to manufacture than the back extrusion by a factor of 2.7 due to the complex machining on the exterior of the part.

3. The tensile properties all easily exceeded the specification minimum for 7079-T6 alloy.

RECOMMENDATIONS

1. Aluminum landing gear forgings should be produced with a hollow barrel section in a manner such that there will be some circumferential grain flow in the barrel wall.
2. Further work should be done to fully develop the back extrusion method using progressively smaller punch diameters.
3. It would be helpful if the landing strut designers could keep the barrel section as free of protuberances as possible to simplify the forging sequence.

BACKGROUND DISCUSSION

The selection of the forming process is essentially a selection of the best compromise among several opposing factors. The desirable compromise is to select a forming method which would yield a part having superior stress corrosion properties to the other methods attempted. Ideally, this method would provide the highest stress corrosion resistance in those areas which are subjected to the highest stress, and would prove to be economically competitive with the original forming method. Although economics is of importance to the method selected, the program is specifically oriented towards improved grain flow characteristics in aluminum aircraft landing gear and in the final analysis may not prove to be the most inexpensive approach.

PART SELECTION

The part selected for this program was a landing gear outer cylinder. This selection was based upon the following considerations:

(1) Landing gear cylinders are particularly susceptible to stress corrosion cracking since they are pressurized and in tension throughout the barrel portion of the forging, residual stresses from heat treatment are often high in this non-symmetric hollow cylinder, and they are intermittently exposed to corrosion environments.

(2) The finish dies were available since production on this part has been discontinued. This resulted in a substantial savings in die cost.

(3) The part size and weight (175 lbs.) met the requirements of the program.

APPROACH TO THE PROBLEM

As mentioned previously, it is really not possible to completely eliminate end grain, particularly in a complex forging such as a landing gear outer cylinder. Thus, the problem becomes one of reducing or eliminating end grain in critically stressed areas by careful control of such factors as stock grain flow, input weight, and open die working prior to closed die forging.

Two general types of grain runout have been found in aluminum alloy landing gear forgings. One type was present in the cylindrical barrel sections and resulted from stock conversion practices.

The other type of grain runout was caused by flashline and internal grain flow associated with the part configuration and closed die forging. The latter is created by forging operations occurring after ingot breakdown and is basically the subject of this program. It is felt that the first source of end grain - i.e., ingot conversion, can be eliminated by careful control of the ingot breakdown practice.

Three different variations in forging techniques were selected which it was felt would significantly alter the grain flow pattern from the original production technique.

Two of these techniques involved cogging and fullering processes followed by finish forging in closed dies. These differ from the production technique in two respects.

(1) In the original production part volume distribution along the length was achieved by upsetting the stock. The new techniques achieve this distribution by starting with a larger diameter stock and working it down.

(2) The production finish forge operation involved rather substantial metal movement and flashing of excess metal. The finish forging operations of the special techniques were more like coining where metal flow and flash were held to a bare minimum.

The third technique involved extrusion of a thick walled hollow cylinder and then machining the final part from it.

The sketches in Figures 1 through 4 outline the forging operations. The planned operational sequences were as follows.

MATERIAL SELECTION & EVALUATION

The stock selected for use in this program was Alcoa 19" round, 7079 alloy, cast lot D850, ingots 33 and 34.

This cast lot had the following % weight composition as determined by spectro chemical analysis at Wyman-Gordon:

Ingot #	Cu	Mn	Mg	Fe	Si	Cr	Ti	Zn	Al
2	.63	.22	3.24	.15	.10	.13	.032	4.41	Balance
10	.66	.23	3.28	.17	.10	.13	.038	4.25	Balance
34	.62	.20	3.32	.15	.10	.14	.054	4.45	Balance
58	.63	.21	3.32	.16	.10	.13	.033	4.14	Balance

All of this material was used prior to completion of the work in Phase II. Hence, another lot of Alcoa 19" round 7079 alloy,. cast lot A662, ingot 39, was utilized to complete this program. Its composition was as follows:

Cu	Mn	Mg	Fe	Si	Cr	Ti	Zn	Al
.56	.17	3.13	.13	.085	.16	.035	3.90	Balance

CONVENTIONAL FORGING METHOD

The starting billet for the conventional method was 7½" round, 90.00" long. The billet was fullered at its center to a 4¼" octagon, 9½" long. The stock was later cut in half forming two single mults as shown in (3) Figure 1.

In the next operation the 7.50" diameter end upset for approximately 3.30" of its length, forming the arms at the large end of the forging shown in (4) Figure 1. The piece, after a caustic etch, visual inspection and conditioning, was placed in the number two upset die and upset with a capped punch forming the bulge shown in (5) Figure 1. The final operation prior to forging in the finish die consisted of a flattening operation in which the piece was flattened to the thickness shown in (6) Figure 1 in a plane parallel to the extruded arms. This operation allowed the stock to be located more readily in the finish die.

PROCESSING

METHOD "A" - CONVENTIONAL FORGING

The starting billet for the conventional method was 7½" round, 40" long. The stock was heated in the #660 Hagan aluminum furnace at 750° for four (4) hours. This is the normal forging temperature for most open die work allowing for some heat build up during the draw operation. The production pieces were cut into single mults prior to the first draw operation. The billets were then drawn to approximately 4¼" octagon on one end for a distance of 4 5/8" (Figure 5).

The 7½" round was then upset for approximately 3.3" of its length forming the arms at the large end of the forging as shown in Figure 6. These pieces, after conditioning and etching, were then ready for the number 2 upset.

The number 2 upset increased the 7½" round to approximately 8.0" round for a distance of 6.0" along the barrel at a distance of 19.5" from the arm end of the forging. This extra material is necessary to satisfy the added volume required to fill the boss on the finish part (Figure 7).

The final operation prior to forging in the finish die consisted of flattening the piece along the entire barrel length. This allowed the stock to be located more readily in the finish die and may be seen in Figure 8.

The finish forging operation was completed on the 18,000 ton hydraulic press using a pressing force of 10,000 tons and a pressing speed of 3 feet per minute. Originally this operation had been run in the 7,700 ton press. However, because of the plan view area of the part (approximately 306 square inches) and the tonnage available on the 7,700 ton press, the maximum force which was obtainable was only 55,500 psi. In view of this, moving the part to the 18,000 ton unit and using a 10,000 ton pressure gave us a pressing force of 65,000 psi, a much more realistic pressure for a part of this size and sophistication.

The actual finishing operation was made in two passes. The piece was loaded in the die, sprayed with Wynns Aluminum Forging Compound and pressed with 4,000 tons. The piece was then lifted out of the die, sprayed both top and bottom with Wynns lubricant, and reforged at 10,000 tons with a 5 second dwell. Forge shop data sheets on the previously described operations may be seen in Tables I through III and a typical finished forged part may be seen in Figure 9.

REGULAR COGGING METHOD

Starting billet for the regular cogging method was 10.00" round, 22.52" long. See (1) Figure 2. Chalk marks shown in (2) Figure 2 indicate the start of the 6.75 and 6.50 diameters. Figure 2 (3) shows the piece after the first rolling operation had been completed. In the final operation, one end was reduced to a 4.25" diameter - See (4) Figure 2. The piece was then cropped to the 46.90" dimension to remove surplus material, caustic etched, visually inspected and conditioned prior to upsetting. The piece was finally upset in the #3 upset die forming the arms shown in (5) Figure 2. The cogged and finish forge diameters were approximately the same.

METHOD "B" - REGULAR COGGING

Starting billet for the regular cogging method was 10.00" round, 22.52" long. The pieces were rolled in standard rolling dies breaking down the 10.00" round to 6.75", 6.50" and 4.25" round respectively. This part may be seen in Figure 10. During the next operation all excessive material was machined from the central boss, leaving only the material necessary to form the boss in the finish die operation. The parts were then hand ground blending all sharp corners and removing all machine marks (Figure 11).

The number 3 upset was a controlled upset operation which gathered stock to form the arms at the large ends of the forgings; the pieces were run on the 7,700 ton press using the 2,000 ton side cylinder. One of these parts is shown after upsetting in Figure 12.

These pieces were subsequently run in the finish die using the following forging procedure: Pieces were loaded in the R-S aluminum furnace at 820°F for four hours minimum heating time. The pieces were then placed in the finish die, sprayed top and bottom, and forged to a 1/2" open die setting. The pieces were then removed to the process inspection area where they were cleaned and ground to remove stock in the boss area of the part to prevent the formation of a lap.

These pieces were then etched and returned to the forge shop and forged in the same manner as described in Method "A". Forge shop data sheets may be seen in Tables IV & V. Photographs of the finished forged parts may be seen in Figure 13.

After finish forging, the pieces were set up on the 4.00" G & L and machined to the process sheet shown in Table VI. These pieces were then moved to a lathe where a steady rest was turned as shown in Table VII. After establishing the center hole and steady rest, the pieces were sent to a hollow bore lathe for hollow boring the 5.00 diameter as shown in Table VIII. The final machining operation was performed on a 4.00" G & L. Here the .75" and the 2.25" diameters shown in Table IV were established completing the machining operations.

OFFSET COGGING METHOD

The stock size used for this method was the same as in the regular cogging method - i.e., 10" round x 22.52" long. The first forging operation was a drawing operation through a "fish belly" or eliptical drawing die to produce the shape shown in (2) Figure 3. The stock was then rotated 90° and passed through these dies a second time. However, this time the dies were held partway open to produce a part as shown in (3) Figure 3.

The offset drawing operation was then performed in two steps using special rolling dies as shown in (4) and (5) Figure 3, and in the isometric sketch 3a. The barrel sections on either side of the central boss were reduced to the 6.75" and 6.50" diameters as shown in (6) Figure 3. Following this operation, the small end was reduced in round cogging dies - (7) Figure 3. The final stock distribution involved the upsetting of the arms on the large end of the forging - (7) Figure 3.

METHOD "C" - OFFSET COGGING

Stock size was 10.00" round, 22.52" long. Using the 7.00" "Fish Belly" or eliptical drawing dies, the stock was drawn along its entire length forming an eliptical shape approximately 7.25" x 10.87". The pieces were then worked through the offset cogging die which left some material un-distributed on one side of the rolled piece. The parts were then fully reworked in standard 6.75", 6.50" and 4.25" round rolling dies forming the part shown in Figure 14. Figure 15 shows the number 3 upset after it has been cleaned up and conditioned and is now ready for the finish die operation.

The finish forge operation was consistant with Method "B" and particular care was taken in maintaining uniformity between the two runs. Handling, lubrication, and forging pressure was consistant in all cases. The pieces from this production run may be seen in Figure 16. Forge shop data may be seen in Tables X and XI.

EXTRUSION METHOD

Here the stock size and weight were somewhat greater than the previous technique. The starting billet was 15.00" round an d 19.00" long. The first forge operation was the pot operation. This was accomplished in a conventional trap pot die which pierced the billet as well as formed the nose section in one operation - (2) Figure 4.

The final forging was an extrusion operation in which the potted piece was placed in an extrusion chamber and forward extruded using a mandrel to form the inside diameter - (3) Figure 4. The extruded part was then placed in a fixture, mounted on a Keller and the finish design - (4) Figure 4, was machined from the extruded shape.

METHOD "D" EXTRUSION

Starting stock size was 15.00" round, 19.00" long. The pieces were machined to the dimensions shown in Figure 17. The billets were machined prior to the pot operation to insure proper location of the start billet in the die.

The machined blanks were subsequently forged in the 18,000 ton hydraulic press using a maximum forge pressure of 7,000 tons and a pressing speed of 1.5 feet per minute. These finish potted pieces may be seen in Figure 18.

In order to assure that the piece did not stick to the mandrel during the pot operation, the following lubrication procedure was used: (1) The piece was sprayed with Richards Forging Compound and the mandrel brought in contact with the piece until a punch penetration of 1/4 of its length had been achieved. (2) The mandrel was withdrawn and reoiled. (3) The mandrel was again brought in contact with the piece until mandrel penetrations of 3/8, 1/2, 3/4 and full mandrel penetration had been achieved, always withdrawing and reoiling between steps. By following this procedure, we were able to form the potted shape in one operation without fear of galling the mandrel or having the mandrel fail during withdrawal.

After a caustic etch and visual inspection, the potted pieces were conditioned in preparation for the extrusion operation.

The pieces were extruded on the 18,000 ton hydraulic forging press using a forge pressure of 4,000 tons and a pressing speed of 1.5 feet per minute. Forge shop data may be seen in Table XII. Figure 19 is a photograph of a typical extruded part.

These pieces, after extrusion, were sent to the layout department where center lines were established. After this operation, the pieces were sent to the machine shop. In the first machining operation, the 2.75" diameter and .75" diameter holes were drilled on a 4.00" G & D horizontal boring mill (See Machining Process Sheet - Table XIII). After completion of the boring operation, the pieces were placed on a tracer lathe and machined to the dimensions shown in Machining Process Sheet - Table XIV (Figure 20 & 21). The pieces were then fixture mounted and set on the Keller ready for machining (Figure 22). After rotating the piece in the fixture and establishing a new tracer combination, the pieces were machined on Side #2 using the Machining Process Sheet in Table XVI and Figure 24.

The finished machined piece may be seen in Figures 25 & 26 and is typical of all pieces made using this technique.

We were able to form the potted shape in one operation without fear of galling the mandrel or having the mandrel fail during withdrawal.

After a caustic etch and visual inspection, the potted pieces were conditioned in preparation for the extrusion operation.

HEAT TREATMENT

The forgings were heat treated in two different lots. The first lot consisted of the four tryout pieces. The second lot consisted of the 15 production parts. All of the forgings, except for one each of Methods "A, B, and C" (S/N's 5, 8 & 12), were fully machined prior to solution treatment. Forgings S/N's 5, 8 and 12 were machined on the outside to the print configuration, but were not bored. This was done so that when these parts were cut for grain flow examination, the macrostructures could be checked throughout the entire cross section. Forging S/N 16, the other part used for macroexamination, already had the major portion of the bore formed by the extrusion operation. The small hole was drilled in this part according to the machining print to prevent the part from floating during quenching.

The same heat treating practice was used on both tryouts and the production run.

The heat treating furnaces were pusher type furnaces fired by natural gas, but using radiant tube heating so that the combustion gases did not come in contact with the forgings (See Figure 27). The heat is transferred from the radiant tubes to the furnace chamber by circulating air.

The solution treating temperature was 830°F - the parts were in the furnace for 12 hours (8 hrs. at temperature) and were then rapidly quenched into agitated 92°F water. Figure 28 shows the forgings loaded on racks ready for the solution treatment.

After observing a five day delay, the forgings were aged at 240°F for a total of 51 hours in the furnace.

Evaluation of Forgings

GRAIN FLOW EXAMINATION

Grain flow sections were cut from forgings produced by Methods A, B, C and D. These forgings (S/N's 5, 8, 12 and 16) were sectioned by bandsawing as shown in Figure 29. The cross section grain flows were faced on a lathe and etched in hot 10% NaOH. They were then rinsed in hot water, dipped in 20% HNO_3 to remove the etching residue, again rinsed in hot water, and finally dried.

The etched cross sections were photographed and are shown in Figures 30 thru 61

These same pieces were cut along the parting plane and one half of each was machined on a shaper and then etched as above. Photographic prints were made of each section and assembled to produce the full parting plane grain flows which were re-photographed. See Figures 62, 63, 64 and 65.

After completion of the parting plane grain flow, the sections were again cut in half longitudinally and machined to produce a section perpendicular to the parting plane. These sections were again etched, photographed and reassembled to produce the grain flows displayed in Figures 66 thru 69.

Comparing the parting plane grain flow sections of forgings produced by Methods A, B and C respectively, there is in general a great similarity in the appearance. The trunnion arms in the Method "A" forging have a somewhat more desirable structure in that the grain flow does not show the abrupt changes in direction seen in the Method B and C forgings. This may be the result of the upset on the Method "A" forging occurring at an earlier stage of the stock shaping operation. The grain flow in the extruded forging trunnion arms is not as pronounced or directional as in the other three, but it is still satisfactory. The barrel grain flow sections perpendicular to the parting plane (Figures 56-69) appear very similar in all four forging methods.

In general, the barrel areas of the first 3 forging methods appear very similar on the parting plane and also perpendicular to the parting plane, if one does not consider the central boss. The barrel locations of the extruded method show a complete absence of the somewhat wavy grain flow noted on parts made by Methods A, B and C.

In the parting plane grain flow just below the central boss area, some change in grain direction is evident in Methods A, B and C. In the Method "B" forging (S.O. 9131) the areas of grain runout due to machining of the central bump can be seen by close examination. However, this grain runout was not as severe as anticipated, probably because of the "ironing effect" from the finish die operation. As expected, there was no change in grain orientation on the extruded piece.

From the general grain flow pattern under the central boss, it can be seen that the two different cogging practices were successful in reducing the amount of end grain in the barrel bore and the severity of the metal flow into the boss. Unfortunately, another problem was introduced which resulted in a more severe grain flow disturbance than in Method "A". On both sides of the central boss (Figures 67 & 68) a severe grain flow eddy can be observed. This disturbance resulted from an improper stock volume and/or distribution in the boss area. Unfortunately, it would be difficult to control this distribution any more accurately than was done during open die working. Thus, if Methods B or C were selected for further development, an additional die set would be necessary to partially form the central boss prior to the final closed die operation.

The cross sectional grain flows in the central boss area (Figures 42 thru 45) reveal some differences. The flash line flow in Method "A" (Figure 42) is the most severe of the 3 forgings while Method "C" is intermediate in severity and Method "B" has the least severe flash line grain runout. Method "D" (Figure 45) had an ideal circumferential flow at the bore and there was no flash line. There was very little evidence of end grain on the Method "B" forging on the side opposite the boss (Figure 43). The flash line comments generally apply to the other cross sectional grain flows in the forging barrels. Figure 70 shows higher magnification photographs (X4) of the flash line in forgings from Methods A, B and C at test ring location RC13. Again, the forgings, in order from most severe to least severe flash line runout, were Method "A", Method "C", and Method "B". It appears that the regular cogging process allowed the closest control of stock input volume in the straight barrel areas.

STRESS CORROSION TESTING

The stress corrosion tests were performed at the Kaiser Alunimum and Chemical Corporation Research Laboratories in Spokane, Washington.

Four (4) fully treated forgings, S/N's 7, 10, 14 and 18, were shipped to Kaiser where the test coupons and rings were cut and machined as shown in Figure 71. For the ring tests, material was machined from both the O.D. and I.D. of the specimen to simulate the finish machined part (Figure 72).

The deflections needed to stress the C-rings to the required stress levels were determined by strain gage measurements. Three (3) 0.5" wide and two (2) 0.75" wide C-rings representing the maximum, minimum and average C-ring diameters were selected for strain gage study. Patterns were made of the inside diameter of each C-ring and an arc of approximately the same length marked on the C-rings.

An etched foil strain gage (SR4 FAP-25-13-S-13) was cemented to the center of the inside of the bore on each of the rings selected for study (Figure 73) . Light punch marks were made 0.01" away from the bore surface on the edge of the C-rings in line with the turn-buckle loading points. Strain gage measurements were made as the specimen was loaded using a stainless steel turn-buckle (Figure 74). A pair of dividers and a steel scale were used to measure the distance between reference points to $\pm$ 0.005".

The results of the C-ring study indicated that the stress on the C-rings varied from 2570 lbs. to 2650 lbs./.01" increase in ring chord length. The C-rings were deflected 0.175" for a stress of 45,000 psi, an error of -0% to +3%.

The templates from the C-ring strain gage samples were used to mark the location of the turn-buckles on the stress corrosion C-rings. The reference points on the stress corrosion C-rings were located as on the strain gage samples.

Figure 75 illustrates the loading frame for the stress corrosion tensile round specimens. An Instron electrical extensometer, Model G-51-16, connected to a Baldwin Type M Strain Indicator, was used to stress these tests. Prior to testing, the entire frame and a portion of the specimen was coated with a paraffin - 10% polyethylene mixture. The stress corrosion testing was the standard alternate immersion test in 3-1/2% NaCl. The immersion was accomplished by loading the specimens in plastic trays and then pumping the corrodent into the trays. After 10 minutes immersion, the trays were drained and the specimens were allowed to dry in air for 50 minutes. The cycle was then repeated.

Prior to starting the test, all of the test specimens were cleaned by etching for 30 seconds in 5% 180°F NaOH followed by rinsing in 50% HNO_3 and distilled water.

The total duration of the test was 30 days. At least once every day during the testing, all of the specimens were examined using a 10X binocular microscope. The time to failure reported was the time in days when the first cracking was observed. The relative humidity of the room air was 40%, the room temperature 80°F and the solution temperature 75°F. The stress corrosion test results are listed in Tables XVII and XVIII.

FIRST TEST GROUP - TABLE I
Tests Initiated August 28, 1967 & Terminated Sept. 27, 1967

All of the C-rings tested at 15,000 psi ran for 30 days with no failures. Thus, the 30 day threshold for stress corrosion cracking on these forgings appears to be above 15,000 psi.

The C-rings loaded at 30,000 psi all had failures in forgings produced by Methods A, B and C. The ring lives averaged somewhat longer in the specimens which were cut 90° from the parting plane as compared with the C-rings cut through the parting plane. None of the ring tests from the extruded forging failed.

At 45 ksi the same trends as in the 30,000 psi tests were present and as might be expected, with shorter lives. Only one of the extrusion C-ring tests failed and this after 26 days. This test (39R) was located adjacent to the end of the extruded bore. See Figure 71 for the test location and Figure 69 for the grain flow. The structure of the material at the point of origin of this test failure is shown in Figure 76 As expected, the cracking is intergranular. The grains in the area of the crack were nearly equiaxed with little directionality.

SECOND TEST GROUP - TABLE II
Tests Initiated Sept. 13 and Terminated Oct. 13, 1967

The test conditions of Group II were identical to those of the first group. Tensile rounds as well as C-ring tests were included. All of the C-ring tests were loaded at 30,000 psi. Test rings 21RA from each forging acted as controls since they came from a straight barrel section 90° from the parting plane. The results of these controls were not significantly different from those listed in Table I. The other ring tests of the second group came from locations around the central boss. Again, all of the extrusion ring tests ran 30 days without failure.

Ring tests 23RA, 24RA and 25RA were all cut directly below the central boss. See Figure 71 . Ring 23RA was directly below the single lug while rings 24RA and 25RA were beneath the double lugs. The 23RA failures were in the center of the ring section as expected, since this is where the grain ran up into the single lug. Rings 24RA and 25RA failed away from the center directly beneath one of the double lugs.

The reason for the inclusion of Methods B & C (regular cogging and offset cogging) into this program was to reduce the amount of end grain at the bore underneath those lugs. However, even though the grain flow directly below the lugs (Figures 66, 67 and 68) had a smaller component away from the bore axis in Methods B & C when compared with Method A, the test results of Method A (conventional forging practice) were generally better than those of Methods B & C.

Specimens for metallographic examination were cut from test rings 23RA and 24RA of Methods A, B and C to try to determine the reason for the reduced properties. These samples are shown in Figures 77 and 78.

Test rings from Location 26, which was 180° from the central lug, were examined from all four methods. It had been anticipated that Method "B" should be the worst in this area since prior to finish forging, the stock gathered midway along the barrel had been machined away exposing end grain. However, this test from Method "B" ran 30 days without failure while Methods A & C both failed. Figure 79 shows the structure of the four (4) 26RC test rings. The microstructures did not give any clue as to the reason for the different behaviors in A, B & C.

The test data for the stress corrosion round specimens reveals some differences for specific locations. The locations in the trunnion arms (Test 40, 41 & 42) all appear to be equivalent as none failed in the 30 day test. Location 43, the transition area from the barrel into the arms, failed at 45,000 psi in all except the extrusion method. This test location was at the flash line and the piece which formed the largest amount of flash (Method A) failed in the shortest time.

The test results of the extruded forging in Locations 45, 46, 48 and 49 were surprisingly good since these tests had a straight transverse flow throughout the test coupons. Tests 50 and 51 appear to be the only locations tested where the stress corrosion results of the extruded forging were inferior to the parts produced by the other three methods. This small end of the forging received little or no work during the extrusion operation and the grain size was rather coarse (Figure 33).

EVALUATION OF TENSILE RESULTS

The individual tensile results from the 4 different forgings representing Methods A, B, C and D were reported in the Third Interim Report without comment. Since that time, average and standard deviations have been computed for straight barrel test locations. These results are listed in Table III.

All of the tensile values exceeded the minimum requirements of AMS4138. The highest transverse strengths were found, as might be anticipated, in the forging produced by extrusion, and appear to be a direct result of the circumferential grain flow. The average long and short transverse strengths were not significantly different within any one forging. However, in the conventionally forged part (Method A), the average long transverse elongation was significantly higher than the average short transverse elongation. This is undoubtedly the result of the strong flash line grain flow in the conventional forging practice.

CONCLUSIONS - PHASE I

1. Except for the small diameter end (top) of the forging, the extruded piece was equal to or superior to the forgings produced by three other practices in resistance to stress corrosion cracking. This is based upon the standard alternate immersion test in 3½% NaCl.

2. Although the radial component of the grain flow beneath the central boss was greatly reduced by the regular and offset cogging methods when compared with the conventional forging practice, there was no apparent improvement in resistance to stress corrosion cracking.

3. Extrusion over a mandrel not only produced a straight, longitudinal grain flow in the parts, but is also produced a circumferential grain flow near the bore surface of the forging. This circumferential flow appears to have substantially improved the resistance of the bore to stress corrosion cracking.

4. All of the tensile test results exceeded the minimums of AMS4138.

PHASE II

Phase II was to consist of a small production run and subsequent analysis to determine the reproducibility of the optimum technique selected. However, because of the prohibitively high cost of manufacturing parts using the forward extrusion technique, coupled with the apparently limited application of such a process, an alternate approach of back extruding and upsetting was recommended for Phase II. This technique combines the advantages of both the closed die forging and the extrusion approaches.

APPROACH

The processing cycle used for the back extrusion is illustrated in Figures 80, 81, 82 and 83. In detail, this processing cycle starts with 6 3/4" rd. x 35.08" long forged billet. Initial breakdown of this billet is from 19" rd. 7079 aluminum ingot rolled to 14 3/8" rd., 10" rd., 8" rd., and finally to 6 3/4" rd. In Step 1 (Figure 80), 4.51" of the 6 3/4" rd. is upset in the No. 3 upset die. This horizontal controlled upset is used to gather stock for the two arms. Following this operation, the part is placed in the finish die for the back extrude and upset operation. This operation is coupled with a forging operation which forms the arms at the head end of the forging - Step 2 (Figure 81). The die used for this operation is the S.O. 9129 finish die which was used in Phase I of the Stress Corrosion Program. This die was modified by machining the 6 3/4" rd. barrel diameter the entire length of the barrel and extending it to the die edge. This removes the nose portion of the forging and permits entry of the mandrel for the extrusion process. The actual forming technique is one of piercing the barrel allowing the material to flow back over the piercing mandrel forming a tube - Step 3 (Figure 82). At some point, approximately 1.16" short of the full stroke, the material hits the loose guide bushing located at the butt end of the mandrel. This forces the remaining material to be upset into the boss cavity forming the finish part shown in Step 4 (Figure 83).

FIRST DEVELOPMENT RUN

Initial stock conversion was made using the same material (cast lot D850 19" rd. 7079) as was used in Phase I. The aluminum ingot was rolled from 19" rd. to 14 3/8" rd., then to 8" rd. and finally to 6 3/4" rd. This conversion process was consistent with the previous conversion practice used in Phase I.

Four single mults, 6 3/4" rd. x 35.08" long, were cut and conditioned for the No. 1 upset operation.

The No. 1 upset was the controlled upset operation and gathered stock to form the arms at the large end of the forgings. The upset was run on the 7,700 ton hydraulic forging press using the 2,000 ton side cylinder and the parts are shown in Figure 84 along with the 6 3/4" rd. rolled stock. The forge shop data sheet may be seen in Table XIX.

One of these forgings was subsequently run in the finish dies. The pieces were loaded in the R-S aluminum furnace at 820°F for 4 hours minimum heating time. The first piece, S/N 1, was then placed in the finish die. The dies were closed using a holding pressure of 4,000 tons. At this point, the side cylinder was actuated and the piercing operation began. When the punch had penetrated approximately 15.00" of the barrel, the forging operation had to be stopped because of interference between the side cylinder ram and the press platten.

The piece was removed from the die and visual examination revealed what appeared to be a "drive through" in the boss located on the barrel. A dimensional check taken at the unit also revealed that the extruded bore was not concentric with the barrel diameter and varied in concentricity by as much as .50" T.I.R. The remaining 3 pieces were removed from the heating furnace until these problems could be resolved. S/N 1 was cleaned and was then sectioned as shown in Figure 85. After machining, these sections were etched in hot 10% NaOH to reveal the grain flow.

Examination of these grain flow slices revealed that although there appeared to be deep laps on the surface, these laps were in fact quite superficial. Although this defect is not very serious from a manufacturing standpoint, it is significant metallurgically.

A careful examination of these macro slices revealed some rather unexpected results. It was originally thought that there would probably be metal movement down into the boss area as the piercing punch passed over it. It was also believed that, should this occur, continued movement of the punch beyond this boss would cause the material displaced by the punch to shear through the boss and separate it from the barrel.

However, contrary to our original belief, it appears that the metal flowed into the boss area (as the punch moved in beyond the boss cavity) and then flowed out of the opposite side of the boss toward the open end of the barrel. The laps caused by this material flow appeared on the surface to be very severe, but were in fact quite minimal as can be seen in Figures 86 through 89. The flow of the material into and out of the boss area does create another rather undesirable effect in that it imparts a wave pattern to the grain flow as it leaves the boss area, thus exposing end grain on the I.D. of the barrel. A section taken through the barrel 180° from the boss shows that the grain was not affected in this area and reflects the type of grain flow which one expects from a piercing operation of this type.

Die changes were made to provide adequate head clearance between the top press platten and the extrusion ram to allow full ram extension. In addition, a plug was machined (See Figure 90) which fits into the boss impression plugging it flush with the barrel diameter. This allows the extruded material to pass by this area without fear of flowing metal down into the impression. Once the punch has passed this area and established a new orifice, the extrusion operation was stopped. At this point, the piece was wash heated. During the wash heat cycle, the plug is removed from the impression, again exposing the boss cavity. The piece was reloaded in the impression and the extrusion operation continued. Since a new orifice has been established beyond the boss cavity, the extruded material flows by the impression without flowing into it. At approximately 1.16" short of the full stroke, the material hits the butt end of the punch upsetting the remaining material into the boss cavity forming the finished part.

SECOND FORGING RUN

Serial Nos. 2, 8 and 9, which were held out of the first forging run because of punch interference between the press platten and side cylinder, were subsequently used in the second forging run. S/N's 2 and 9 were forged using a two step operation involving one wash heat. S/N 8 was back extruded in one operation thus allowing material to flow into the boss area in the same manner as S/N 1.

After examining a macro-etched section from S/N 1, it was believed that perhaps insufficient material flowed through the boss and this was why the shearing which did occur was not extensive. S/N 3 was run to reproduce, if we could, the same condition we created in S/N 1. We could, in fact, by continuing the full stroke to completion, magnify this condition and visually display the worst condition that this technique would produce.

S/N 8 was subsequently cut and macro sections were cut through the boss area. Examination of these macros did reveal the occurrence of severe shearing through the boss area. This shearing, which is caused by material flowing through the boss after it has been filled, can be graphically seen in Figures 91, 92 and 93.

Examination of the macro taken through the heaviest section of the boss revealed the shear extending through approximately 75% of the boss length with very severe flow lines continuing beyond that point. The macro taken through the narrower portion of the same boss shows this same shear extending almost through its entire length.

S/N 9 was also cut in these same areas to examine the metal flow which occurred in these same areas when using the plug approach. This is a two step operation using one wash heat, with the extrusion and upsetting being done at separate times. In the first step, a plug is placed into the boss impression plugging it flush with the barrel diameter. This allowed the extruded material to pass this area without material flow into the boss impression. Once the punch had passed this area and established a new orifice, the extrusion operation was stopped. The piece was then removed from the die and wash heated. The plug was removed from the impression, again exposing the boss cavity. The extrusion was then continued allowing the material to flow back along the punch until at some point, approximately 1.16" short of the full stroke, the material hit the butt end of the punch upsetting the remaining material into the boss cavity. Both S/N's 2 and 9 failed to yield a good part because they lacked the necessary volume required to fill the part.

After cleaning these pieces, a close inspection revealed the following:

1. By removing the plug too soon after a new orifice is established, a peel down problem is created. S/N 2 vividly illustrates the type of peel down which is experienced during the second operation. Even though the plugging has eliminated the flow of material down into the boss cavity directly, enough material flows by this area causing a fin to be created as the material flows over the radius at the back end of the boss causing the peel down shown in Figure 91.

2. The rapid flow of material up into the boss area causes the material to pull away from the punch initiating the beginning of a lap. S/N 9 was cut as shown in Figure 91 and photomacrographs taken of these areas may be seen in Figures 94 and 95. It was not known at this point to what extent or degree the forming of this lap would extend in a fully formed part, but it was suspected to be quite severe.

The problems associated with this process were not considered insurmountable and in most cases a fix would be easily initiated. In order to eliminate the peel down, it would seem that merely allowing the extrusion operation to continue until its final length is attained before removing the plug would remedy this problem. The lap, it was felt, could possibly be prevented by forming the boss in several steps using plugs of various degrees of fill. Forge shop data sheets of these pieces may be seen in Table XX.

THIRD FORGING RUN

Four (4) pieces of stock were cut in preparation for the third forging run. These pieces were cut to a new cut length of 37.50" $^{+.25}_{-.00}$. This was approximately 2.50" longer than the previously cut pieces and would satisfy the volume requirements of the part. These pieces were assigned S/N's 3, 4, 10 and 11. The pieces were then conditioned and readied for the No. 1 upset.

The 4 pieces were run on the 7,700 ton hydraulic forging press using the 2,000 ton side cylinder. The forge shop data sheet may be seen in Table XXI. All 4 pieces were subsequently cleaned up and readied for the back extrude and upset operation.

S/N's 3, 4, 10 and 11 were loaded in the R-S aluminum furnace at 820°F for 4 hours minimum heating time. The first piece, S/N 4, was placed in the finish die and held with a 7,700 ton pressure. The back extrusion operation was begun and the piece extruded until it had attained its desired extruded length. At this point, the extrusion operation was stopped and the punch withdrawal began. It was at this point that the punch failure, which is shown in Figure 96 was experienced. The forging was discontinued at this point and the 3 remaining pieces removed from the furnace.

The aluminum forging was bandsawed along the barrel and the extrusion punch removed for examination. A dimensional layout of the punch revealed a bow of .090" from a point at the butt end of the punch to a point at the extreme nose of the punch in one plane only. This bow was at 90° to the parting plane. It was this bend in the punch which caused the failure during withdrawal. This bend was caused by improper location of the guide ring during the initial set up. It is believed that the guide ring was placed too close to the die edge so that the unsupported portion of the punch at the nose end was not concentric with the barrel diameter. This lack of concentricity permitted the punch to start the extrusion at a slight incline to the parting plane. As the extrusion stroke was continued, the guide ring forced the back end of the punch to remain concentric with the barrel diameter causing the punch to bend in the manner described.

FOURTH FORGING RUN

Three (3) pieces of stock were readied for the fourth forging run. They were S/N's 3, 10 and 11. All pieces had been upset previously and were conditioned properly for the back extrude and upset operation.

S/N 10 was selected to be the first piece forged. Care was taken to properly locate the guide ring to eliminate the possibility of damaging the punch as in S/N 4 of the previous run. A holding pressure of 7,700 tons was applied and the extrusion operation began. In order to provide the best possibility of success, it was decided to use multiple pushes with two interim steps before completing the back extrusion operation. The punch was allowed to penetrate a 5" depth and then was withdrawn and reoiled. On the second pass, the punch penetrated an additional 7" and again was withdrawn and reoiled. On the third pass, the punch was permitted full penetration. When punch withdrawal was started, the die stops which hold the dies in a fixed position failed. Holding pressure of 4,000 tons was exerted on the dies and withdrawal was again attempted. The punch, rather than extracting itself from the forging, caused the extrusion to fail in much the same manner as one pulls a tensile specimen. This failure may be seen in Figure 97. Examination of the punch showed it to have upset during the extrusion operation. A slice was taken of the punch material and hardness checks taken. Readings of Rc28-30 were recorded. Punch specification listed on the print required that the punch material be 4340 material heat treated to Rc42-45. Punch failure was, therefore, attributed to insufficient punch strength due to improper heat treatment.

Two new punches were designed to insure freedom from punch failure. One punch would be used for the upset operation. The extrusion punch was relieved a short distance beyond the nose to reduce the extrusion pressure required to form the part. Material for the punch was H-11 heat treated to Rc50-52. The second punch was to be used for the upset operation only with sufficient strength to prevent failure.

FIFTH FORGING RUN

The program's remaining forging stock was cut and serial numbers assigned. There was enough material remaining in the program to yield 6 pieces at 38.00" long. These pieces were assigned S/N's 5, 6, 7, 12, 13 and 14.

These pieces were properly chamfered, conditioned, and subsequently formed in the No. 1 upset die. All pieces forged very well, filling the impression nicely, and no problems were encountered during this operation. Photographs and forge shop data sheets may be seen in Figures 98 & 99 and Table XXII.

S/N's 5, 6, 7, 12, 13 and 14 were subsequently back extruded using the newly designed H-11 punch and no problems were encountered. These pieces were then reloaded for a wash heat during which time the punch was changed for the upset operation. Average pressure required for the back extrusion operation was approximately 400 tons or a stem pressure of 62,000 psi. The forge shop data sheet may be seen in Table XXIII.

S/N's 5, 11, 13 and 14 were subsequently put through the upset operation with reasonable success. Although none of the pieces filled completely, it did demonstrate that the approach was a practical forging technique. During this forging operation a valving problem on the 7,700 ton press was encountered. Due to leakage in the system, we could not maintain adequate holding pressure on the die system causing the dies to part during the upset operation. This permitted metal to flow out as flash, starving the boss area of the necessary material required to fill the impression. These pieces may be seen in Figures 100, 101,102 and 103. The degree of underfill is shown graphically in the sketches shown in Figures 104, 105 & 106. The forge shop data sheet of these parts may be seen in Table XXIV.

In addition to this problem, an additional difficulty was encountered. During the upset operation, a thin fin of metal was driven between the punch and the loose guide ring. This fin is created when the material which is forced up against the guide ring is forced to reverse itself. At this point, it extrudes a fin between the punch and guide ring which all but welds the guide ring to the punch. On S/N's 5, 11 and 13 we were able to loosen the ring from the punch by pinching it in the die with some asbestos and withdrawing the punch with the dies under pressure. This scarred the punch with each attempt to free it and eventually on S/N 14 siezed so tightly that it caused the punch to fail by upsetting.

The guide ring was redesigned as a split ring so that it could be separated after each upset operation eliminating the stripping operation which caused the punch failure. In addition, two guide rings of different lengths were made to give some flexibility in controlling the length of stroke necessary to form the boss.

A concentricity check was made of S/N's 2, 8 and 9 of the second forging run and S/N's 11, 13 and 14 of the fifth forging run (see Figures 107 through 112). Careful study of these layouts indicate that the guide ring does locate the punch fairly well initially. Comparing those pieces run in the second forging run with the pieces run in the fifth forging run, it becomes quite evident that the positioning of the guide ring is very important. In those pieces (S/N's 2, 8 and 9) in which the guide ring was placed some distance from the end of the forging, the concentricity at point (2) is quite poor (as bad as .21 T.I.R.). On S/N's 11, 13 and 14, the pieces which had the guide ring butted up against the forging prior to extrusion, the concentricity is considerably better, as little as .03 T.I.R. However, at the end of the extrusion (Point 1) concentricity is poor on all pieces. This problem is directly related to the mechanical condition of the press. There is enough play in the press ram to permit the ram to sag slightly causing the punch to slope when in position for extruding. This slope is approximately 1/2 to 1°. The degree of eccentricity caused by this angle does not pose a major problem from a forging envelope standpoint since there is adequate coverage to prctect the machined part. It is, however, instrumental in creating tool problems and is possibly responsible for some of our tool failures. For this reason, these tools were redesigned to adapt to the 25,000 ton press. This unit is much more ridged and will eliminate any concentricity problems.

The final forging run of 5 pieces was made on the 35,000 ton press using the newly designed inserts, punch holder and split guide ring designs. These 5 pieces were processed through the No. 1 upset on the 7,700 ton forging press and conditioned prior to the extrusion operation. The pieces were loaded in the R-S aluminum furnace at 820^{o}F for 4 hours minimum heating time. They were placed in the finish dies which were closed using a holding pressure of 10,000 tons. The side cylinder was then activated forming the extruded barrel tube. During this operation the filler plug shown in Figure 90 was used to prevent the extruded material from flowing down into the impression. At this point, the pieces were wash heated. During this time the insert plug was removed from the die and the larger of plugs shown in Figure 113 inserted preparing it for the first upset operation. These pieces were then restruck in the finish die partially forming the boss as shown in Figure 114. The forgings were subsequently conditioned and black etched for the next forging operation.

Using the inserts and the split floating guide ring shown in Figure 113 the pieces were restruck in two passes using the inserts forming the part shown in Figure 115 Chronologically, the part is pressed using the larger of the two inserts after which the piece is conditioned. The large insert is removed using the tee handle shown in Figure 115 and replaced with the smaller of the two inserts and the piece restruck. Again, the piece is wash heated. In the final pass, the last insert is removed leaving the boss cavity unobstructed allowing the boss to be completely filled forming the finished part.

Care must be taken during each upset operation to be sure that the impression is filled completely before withdrawing the punch. This irons out any lap which might be starting to form under the boss at the bore diameter and prevents carrying some of this lap into the next operation, thereby compounding the problem and causing laps similar to those shown in Figures 116 & 117. If this precaution is observed, satisfactory fill in of the central boss can be achieved.

HEAT TREATMENT

All of the forgings heat treated (Nos. 21, 24 & 30) were machined on the outside of the barrel and in the bore to the print dimensions.

The forgings were loaded with the bore axis vertical. The solution treatment and age were the same as in Phase I - 830°F for 12 hours followed by a rapid quench in 90°F water. After a five day delay, the parts were aged at 240°F for 48 hours (51 hours in the furnace).

TENSILE TESTING

PHASE II

Forging S/N 21 was cut for tensile evaluation as shown in Figure 118. All of the tests except for locations 29 and 30 were standard .250" diameter tests. Tests 29 and 30 had a standard test configuration with a .505" diameter.

All of the tests easily exceeded specification minimums for 7079 T-6. The test results are listed in Table XXV.

TABLE XXV

Results of Tensile Tests from Phase II Forging S/N 21 Produced by the Back Extrusion Method - Test Locations are shown in Figure 127

Test Location	Yield Strength 0.2% Offset-KSI	Ultimate Tensile Strength - KSI	Elongation % in 4D
1	67.2	77.9	11.0
2	66.2	76.4	10.5
3	66.0	76.5	9.5
4	68.0	78.4	10.0
5	69.4	79.2	10.0
6	68.5	78.6	11.0
7	67.0	77.4	12.5
8	68.6	78.9	12.5
9	69.2	79.2	12.5
10	70.0	78.8	11.0
11	70.6	79.8	11.0
12	70.8	80.0	12.5
13	71.5	80.6	11.0
14	71.2	80.3	10.3
15	70.0	79.3	10.5
16	68.0	77.9	10.0
17	71.0	80.6	12.0
18	70.0	79.6	10.5
19	68.1	77.6	11.0
20	68.5	78.2	10.0

TABLE XXV (continued)

Test Location	Yield Strength 0.2% Offset-KSI	Ultimate Tensile Strength - KSI	Elongation % in 4D
21	69.2	79.2	12.0
22	68.8	78.2	12.0
23	69.5	78.8	12.0
24	68.2	77.4	11.0
25	70.0	78.8	11.0
26	69.0	78.0	11.5
27	70.0	78.2	10.0
28	70.6	79.0	10.5
29	67.0	77.0	7.0
30	66.7	76.0	7.0
31	65.6	77.2	16.0
32	65.5	76.2	11.5
33	65.0	74.2	14.5
34	66.8	76.2	14.5
35	75.0	80.0	13.0
36	76.0	83.4	11.5
37	75.0	82.4	12.0
38	77.4	84.7	12.0
39	69.5	79.3	9.9
40	66.0	77.6	12.5
41	67.0	78.0	11.5
42	65.0	76.5	10.6

TABLE XXV

Test Location	Yield Strength 0.2% Offset-KSI	Ultimate Tensile Strength - KSI	Elongation % in 4D
43	64.5	75.7	10.0
44	66.5	75.0	10.2
45	69.5	79.0	12.7
46	70.0	79.8	10.2
47	74.9	82.4	13.0
48	72.2	80.4	14.0
49	74.0	82.3	13.0
50	76.8	84.0	11.0
51	69.6	77.9	14.0
52	75.0	83.0	11.5
53	73.0	80.6	13.0
54	74.2	81.8	12.5

PHASE II GRAIN FLOW EXAMINATION

Grain flow sections were cut from forging No. 33 by band sawing and were then prepared for examination by machining and etching. See Figure 141 for method of sectioning grain flows.

These sections are shown in Figures 119 through 139. Figure 140 is a composite grain flow on a plane perpendicular to the parting plane.

In the forging barrel sections on a plane perpendicular to the parting plane and parallel with the bore axis, the grain had a relatively straight moderate longitudinal flow. The several sections perpendicular to the bore axis displayed an essentially equiaxed fine grained structure with some slight indication of directionality in the circumferential direction. There was some slight runout at the parting plane, but its effect was confined to an area not more than 1/8" in diameter at the flash line.

Certain forging defects were also readily visible. The remnants of the forging lap and associated grain flow disturbance were quite pronounced beneath the central boss (See Figure 138). All of the lap would be removed by machining to the finish bore dimension, but the grain flow disturbance would remain. It is, however, debatable as to the effect of this grain flow disturbance on the part performance since any stress corrosion cracking which might initiate at the inner bore surface would have to cross a pronounced longitudinal grain to penetrate the cylinder wall.

Other grain flow defects were noted toward the bottom of the bore near the limit of the punch penetration. These defects occurred as a series of laps which are believed to be associated with the repeated punch penetration necessary to form the central boss in a stepwise fashion. Some of these laps penetrated below the finish machine dimensions in most of the parts produced. However, since they were nearly parallel with the bore wall, the associated grain flow disturbance was minimal.

PHASE II - STRESS CORROSION TESTING

The testing of the Phase II forgings was carried out using the same procedures as in Phase I. The test locations and identifications were essentially the same as those in Phase I. There were, nevertheless, some differences in testing conditions. Figure 142 shows the locations of the stress corrosion tests.

The test loads were increased by 15,000 psi in the Phase II testing since there were no failures in any of the tests at the minimum (15,000 psi) stress level in Phase I. Thus, the Phase II tests were conducted at 30,000, 45,000 and 60,000 psi loads. In addition, the testing was carried out for a period of 90 days instead of the 30 days which was used in Phase I. Furthermore, a series of ring tests were taken with the O.D. in tension (Tests 60R - 68R).

The tests in Phase II were taken from two different forgings. This was done for various reasons. Forging S/N 24 was from the same cast lot as the parts tested in Phase I. However, it was not completely filled in the central boss location, so that tests from this area could not be taken. The forgings produced after S/N 24 were from another cast lot, and as they were the only parts available with a central boss which was properly filled, the stress corrosion testing on this portion of the forging had to be performed on one of these parts. S/N 30 was selected.

To insure that the tests from forging #24 and #30 could be compared directly, additional barrel ring tests were tested from locations 27R - 36R in forging #30. Table XXVI lists the stress corrosion test results from these two forgings in identical test locations. There does not appear to be any significant differences between the two. The complete test results are listed in Tables XXVII & XXVIII.

Of all the stress corrosion tests taken from forgings 24 and 30 which were back extruded in Phase II, only two tests failed in less than 90 days at a 30,000 psi load. Both were ring tests - 3R (S/N 24) - which failed in 33 days and 24R (S/N 30) which failed in 44 days. Ring 3R was located adjacent to the arms at one end of the forging. Figure 143 shows the grain flow at the fracture of this test. Shows lack of circumferential flow in this area. The structure is typical of conventional forgings.

Test location #24 is directly below the central boss. Figure 144 shows the grain structure at this location. Flow goes up into boss in this location producing short transverse test conditions on fracture plane.

Considering only the barrel ring tests with the bore in tension, the stress corrosion test lives decreased with increasing load. This is summarized below where the percent of tests which failed in less than 20, 40, 60 and

90 days are tabulated along with the test loads.

Cumulative % Failures

Test Load	20 days	40 days	60 days	90 days
30 ksi	0	7%	7%	7%
45 ksi	0	10%	30%	40%
60 ksi	30%	70%	100%	100%

TABLE XXVI

Comparison of Stress Corrosion Ring Life in Identical Location from Forgings No. 24 & 30. Cast Lots D850 & A662:

Test Location	Test Load	S/N 24	S/N 30
27	30 KSI	O.K.	O.K.
28	45 KSI	40	O.K.
29	45 KSI	O.K.	O.K.
30	30 KSI	O.K.	O.K.
31	60 KSI	14	22
32	30 KSI	O.K.	O.K.
33	60 KSI	49	9
34	30 KSI	O.K.	-
35	45 KSI	O.K.	63
36	60 KSI	8	21

TABLE XXVIII

Stress Corrosion Results - S/N 30. Testing Procedure - Standard Alternate Immersion Test in 3.5% NaCl - 90 days (1)
Part II. C-Ring - I.D. Tension:

Specimen No.	Specimen Type	Load (2) psi	Failure Time Days (3)
23R	C-Ring	30,000	O.K.
24R	"	"	44
25R	"	"	O.K.
26R	"	"	"
27R	"	"	"
28R	"	45,000	"
29R	"	"	"
30R	"	30,000	"
31R	"	60,000	22
32R	"	30,000	O.K.
33R	"	60,000	9
35R	"	45,000	63
36R	"	60,000	21
44	Tensile Round	30,000	O.K.
45	" "	"	"
46	" "	"	"
47	" "	45,000	70
48	" "	"	O.K.
49	" "	"	44

TABLE XXVIII

Test initiated February 3, 1969 and Terminated May 5, 1969:

(1) 90 day - 3.5% NaCl alternate immersion (10 min. wet/50 min. dry each hour). Solution temperature: 75°F. Relative humidity during drying: 40% ± 5%. Air temperature: 80°F. Specimens were prepared for testing by etching 30 seconds in 5% NaOH at 180°F, desmutted in 50% HNO_3.

(2) The deflection needed to stress the C-Rings was determined from earlier strain gage measurements. (Re: P.O. 22591, MCG 282 I.)

(3) Samples examined daily at 10X and removed if one or more cracks detected or if completely fractured. O.K. - designates no failures in 90-day test.

TABLE XXVII

Stress Corrosion Results - S/N 24. Testing Procedure - Standard Alternate Immersion Test in 3 1/2% NaCl - 90 days (1) Part I:

Specimen Number	Type	Load (2) (PSI)	Failure (3) Time - days
1R	Ring - I.D. Tension	30,000	O.K.
2R	" " "	"	O.K.
3R	" " "	"	33
4R	" " "	"	O.K.
5RB	" " "	60,000	27
6RA	" " "	30,000	O.K.
7RB	" " "	45,000	O.K.
8RD	" " "	30,000	O.K.
9RA	" " "	45,000	O.K.
10RC	" " "	60,000	22
11RB	" " "	30,000	O.K.
12RD	" " "	45,000	O.K.
13RA	" " "	30,000	O.K.
14RC	" " "	45,000	O.K.
15RB	" " "	60,000	22
16RD	" " "	30,000	O.K.
17RA	" " "	60,000	57
18RC	" " "	45,000	41
19RB	" " "	60,000	41
20RD	" " "	45,000	22

TABLE XXVII

Specimen Number	Type	Load (2) (PSI)	Failure (3) Time - days
21RA	Ring - I.D. Tension	30,000	O.K.
22RC	" " "	60,000	22
27RB	" " "	30,000	O.K.
28RD	" " "	45,000	40
29RA	" " "	45,000	O.K.
30RC	" " "	30,000	O.K.
31RB	" " "	60,000	14
32RD	" " "	30,000	O.K.
33RA	" " "	60,000	49
34RC	" " "	30,000	O.K.
35RB	" " "	45,000	O.K.
36RD	" " "	60,000	8
37RA	" " "	45,000	68
38RC	" " "	60,000	10
60RD	Ring - O.D. Tension	30,000	O.K.
61RA	" " "	45,000	6
62RB	" " "	60,000	5
63RC	" " "	45,000	23
64RD	" " "	30,000	O.K.
65RA	" " "	60,000	5
66RD	" " "	30,000	33

TABLE XXVII

Specimen Number	Type	Load (2) (PSI)	Failure (3) Time - days
67RA	Ring - O.D. Tension	45,000	14
68RB	" " "	60,000	2
40	Tensile Round	30,000	O.K.
41	" "	30,000	O.K.
42	" "	30,000	O.K.
43	" "	30,000	O.K.

TENSILE RESULTS

The tensile properties of all of the forgings produced exceeded AMS4138 specification minimums. The mean and standard deviations were determined for several test locations in the straight barrel section in the three major test directions with the following results:

1. The longitudinal test direction means and standard deviations were not significantly different for the five different forging practices.

2. The mean long transverse test yield and ultimate strengths were somewhat higher in the two extrusion methods when compared with the other forging practices and the elongations in the back extruded forging were the highest of the group.

3. The same differences which were noted in the long transverse test direction were again noted for the short transverse tests.

COST COMPARISON

In order to determine the relative costs of the various production methods, a cost per piece was developed based upon the production of 100 parts. The cost of a complete set of tools was included for each method and this cost was amortized over the 100 piece run.

Using this method of pricing, the following relative costs were developed after assigning the conventional forging practice a relative cost of 1.000.

	Relative Cost
METHOD A - Conventional Forging	1.00
METHOD B - Regular Cogging	.98
METHOD C - Offset Cogging	.97
METHOD D - Extrusion	2.21
PHASE II - Back Extrusion	.82

Methods A, B & C are quite close in costs with "A" being somewhat more expensive because of the two upsetting operations. Method "D" is much more expensive for three major reasons - (1) The tooling was larger and more expensive (2) The part had to be forged on a larger press and (3) Intricate machining necessary over almost the entire outer surface of the forging. The latter was responsible for over 85% of the cost difference.

The back extrusion method proved to be the least expensive operation primarily because of the lower stock input weight.

DISCUSSION

Stress Corrosion Results

The stress corrosion test results from forging 24 revealed little influence from the parting line. This is as expected since the barrel was formed by back extrusion and the only flash present was formed when the dies separated slightly during the extrusion operation.

In the barrel section of the forging, the Phase II (back extrusion) test results were generally either equal to or superior to those of the forgings produced by conventional, regular cog or offset cogging practices. This is believed to be due to the finer grain size and the slight circumferential grain flow of the back extruded part. The forward extruded part had stress corrosion properties which were equal to or somewhat better than those of the back extruded part. This is likely the result of a more pronounced circumferential grain flow in the forward extrusion. This in turn may be due, at least in part, to the larger punch (4.50" in the forward extrusion - 4.00" in the back extrusion) and thinner barrel wall in the forward extrusion.

This difference in stress corrosion resistance was also reflected in the stress corrosion tests in which the outside of the barrel was placed in tension . The forward extrusion again was superior.

Thus, the results of this testing indicate a definite improvement in resistance to stress corrosion cracking when a tubular forging barrel was formed by an extrusion process as opposed to conventional forging practices which produced a solid barrel section.

Design Considerations

Work completed in Phase I of this program has shown a definite superiority of the extrusion method over the other three forging practices examined in resistance to stress corrosion cracking. However, the extrusion method employed required extensive machining of the finish forging which made this method more expensive, time consuming, and wasteful of material.

Because of this, the work in Phase II was carried out on a modified extrusion method which was expected to produce parts requiring very little machining and yet retaining the improvement in stress corrosion resistance noted in the extruded parts made in Phase I.

Although we were able to manufacture several parts using the back extrusion method developed in Phase II, there still exists several mechanical problems associated with this technique. The punch ratio which we were committed to use because of the part geometry was 11.3 diameters. This is considerably more than the recommended 6.5 diameters suggested in most design manuals. This was responsible, at least in part, for most of the punch failures which we experienced. This problem has been overcome to some degree by using higher strength punch materials and by redesigning using two punches and a loose guide ring. In addition to these changes, the dies were modified to enable us to move the job to the 35,000 ton press. This increased the rigidity of the die system in addition to correcting the alignment problem we experienced in the 7,700 ton press. By using two punches, one for the back extrusion operation with a relief behind the punch nose, and one tapered punch for the upset operation, we were able to reduce the required extrusion pressure and extend the punch life during the extrusion and upset operations. We reduced further the possibility of tool failure by designing the loose guide ring which can break away from the punch in the event a fin should be formed between the punch and the loose guide ring. This finning had been responsible for a punch failure in an earlier run. When considering this forging technique for future applications, the punch diameter to length ratio should be kept within the acceptable limits recommended.

On several pieces, peel down was observed at the bottom of the bore. This peel down results as the bore diameter is reduced in diameter as hold down pressure is applied prior to the upset stroke. As the punch enters the bore for the upset operation, the punch now being slightly larger than the bore, it rolls a small amount of material down the bore in front of the punch depositing at the end of the bore. By the time the third upset is completed, the accumulation of this material is quite significant and creates a very severe defect in that area. In most cases, this defect is machined out in the subsequent heat treat machining operation; however, in some cases its severity is too great to be cleaned out completely. This can be corrected in several ways by either using multiple punches of descending sizes or by increasing the taper on the punch or perhaps by inserting the punch just short of full penetration prior to applying the hold down pressure.

The lap which occurred at the bore directly below boss is formed during the upset operation. This was the result of an undesirable relationship between the extruded wall thickness and width of the cavity opening. In this particular case the ratio 2.72 : 1 was used. This is much higher than the 1 : 1 ratio recommended. A series of inserts used in multiple passes were used to overcome this defect. This corrective measure permitted us to eliminate in most cases this defect or to minimize it sufficiently, so that it was removed by subsequent machining.

Although there are certain design problems associated with this forging technique, these problems are minimal and should not prevent this technique from being applied to other applications. Landing gear parts whose parameters will permit the use of this technique should be made using this approach. Stress corrosion properties from parts made in this manner could be expected to be superior to those made using conventional forging practices.

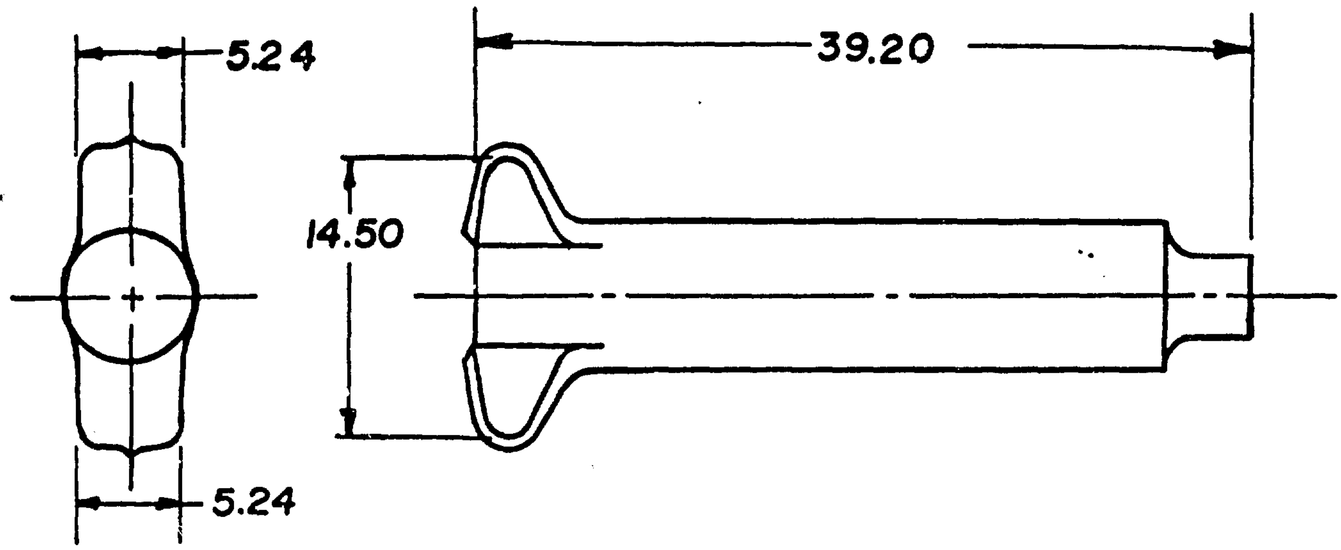
TABLE I

FORGE SHOP DATA SHEET FOR METHOD "A".

NUMBER I UPSET OPERATION.

Furnace Temperature : 750°F

Lubrication: White and Bagley forging compound



Serial Number	39.20	5.24	5.24	14.50
5.	40.07	5.28	5.28	14.50
6.	40.48	5.26	5.30	14.50
7.	39.90	5.26	5.26	14.50

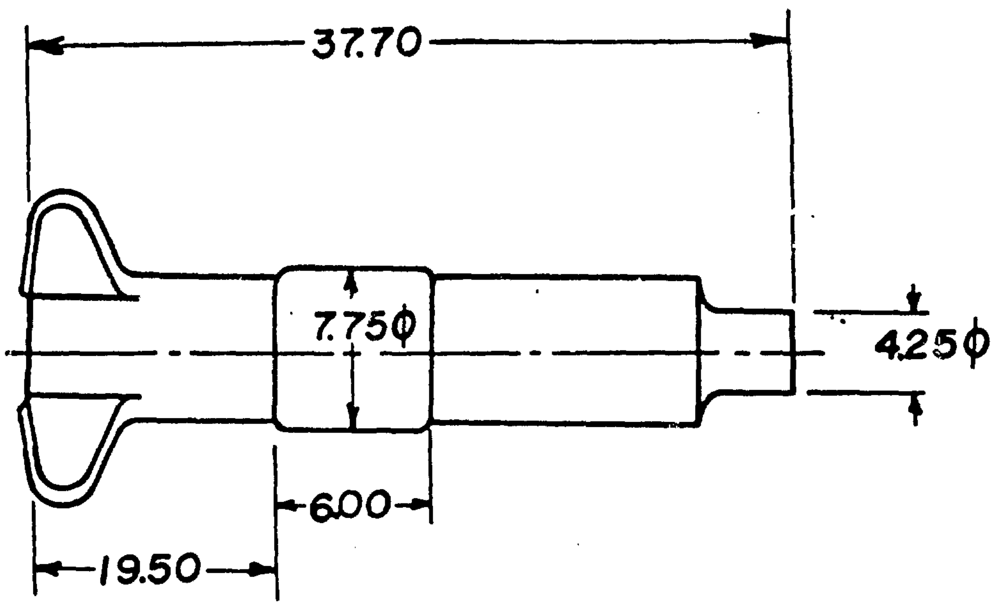
TABLE II

FORGE SHOP DATA SHEET FOR METHOD "A".

NUMBER 2 UPSET OPERATION.

Furnace Temperature: 750°F

Lubrication: White and Bagley forging compound



Serial Number	37.70	19.50	6.00	7.75	4.25
5.	37.82	19.50	6.00	8.00	4.25
6.	37.70	19.50	6.12	7.82	4.25
7.	37.75	19.50	6.08	8.00	4.25

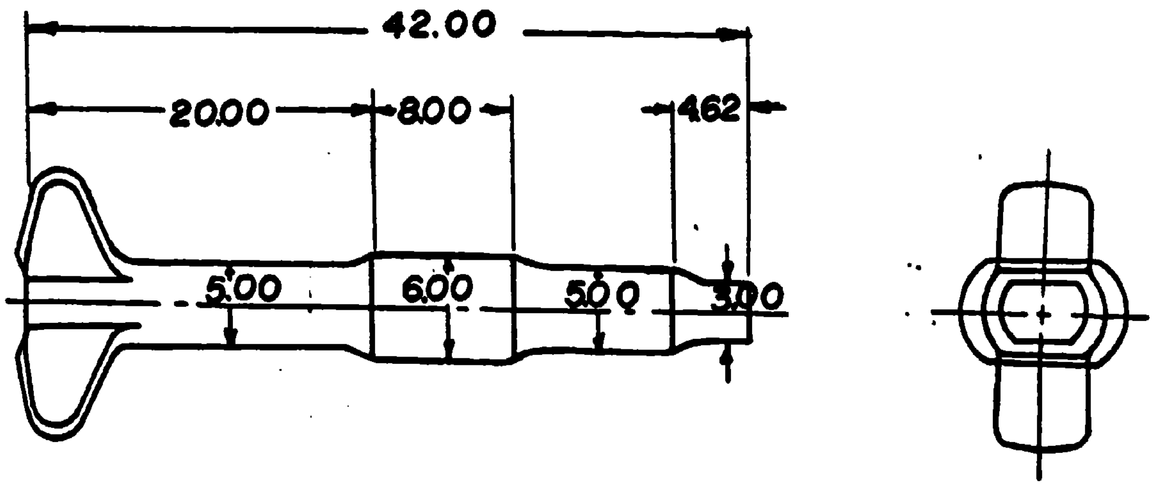
TABLE III

FORGE SHOP DATA SHEET FOR METHOD "A".

FLATTENING OPERATION.

Furnace Temperature : 820°F

Lubrication : None



Serial Number	42.00	20.00	8.00	4.62	5.00	6.00	5.00
5.	42.12	20.00	7.75	4.62	5.00	6.00	5.00
6.	42.00	20.00	8.00	4.75	5.00	6.04	4.95
7.	42.25	20.00	8.00	4.50	5.06	6.00	5.02

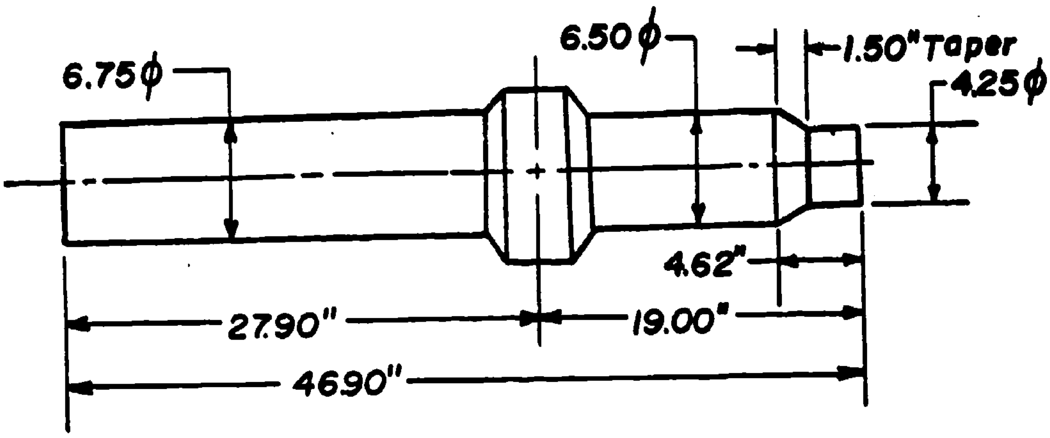
TABLE IV

FORGE SHOP DATA SHEET FOR METHOD "B".

ROLLING OPERATION.

Furnace Temperature: 750°F.

Lubrication: White and Bagley forging compound (swabbed on dies only).



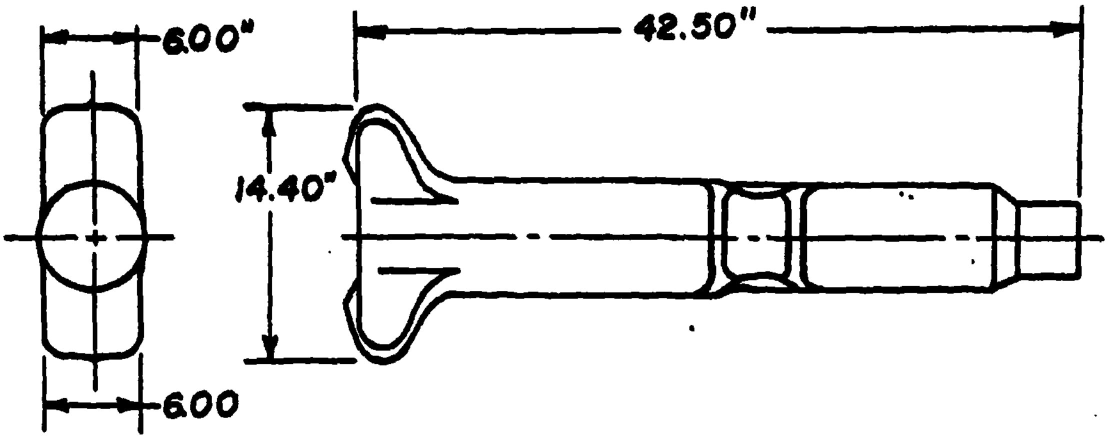
Serial Number	6.75	6.50	4.25	4.62	19.00	46.90	1.50
8.	6.80	6.42	4.25	6.00	20.50	47.50	2.25
9.	6.80	6.42	4.25	5.60	21.30	47.40	2.25
10.	6.80	6.42	4.25	5.90	20.60	47.50	2.12
11.	6.80	6.42	4.25	5.90	20.50	47.50	2.2[illegible]

TABLE V

FORGE SHOP DATA SHEET FOR METHOD "B".
NUMBER 3 UPSET OPERATION.

Furnace Temperature: 750 °F.

Lubrication: White and Bagley forging compound.

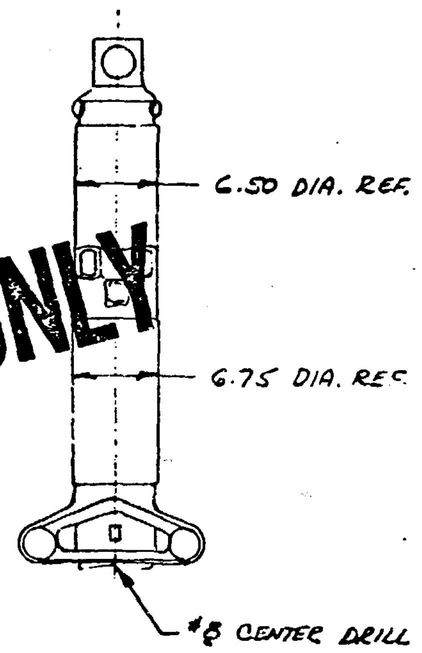


Serial Number	42.50	6.00	6.00	14.40
8.	42.50	6.02	6.06	14.16
9.	42.50	6.00	6.04	14.25
10.	42.50	6.00	6.00	14.25
11.	42.50	6.00	6.04	14.40

TABLE VI

RGGT | Sheet 1 of 4 | W.G. No. S.O. 9130-1-2

OPERATION CODE 750	DESCRIPTION SET UP CODE 751	RPM / FEED
	Original set up to center drill arm end. Set forging in vee blocks, line up and level to layout. Strap over vee blocks	
1	Center drill arm end of part.	600
	TOOL # 1 # 8 Center Drill	Hand
2	Remove burrs.	



REFERENCE ONLY

DB

All dia's to ___ within ___
All dia's not noted ___
Surface finish ___
Denotes stamping location

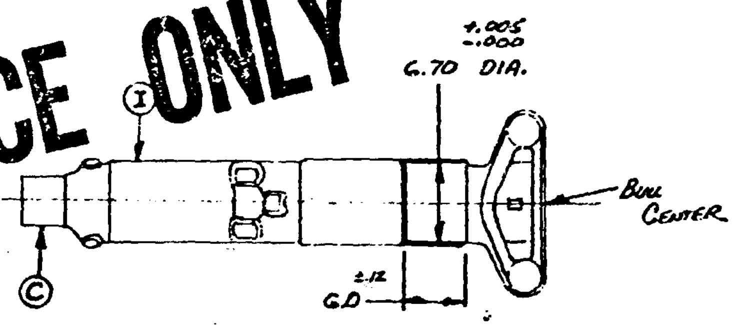
EQUIPMENT 4" G & L			MATERIAL Aluminum 7079-T6
WG	SHOP	CUST	FC# SHOP
DATE 4-14-67	CHKD WCY	APPVD	WG / CUST

Worc. Form 722B (Rev. 12/66)

TABLE VII

ROOT	Sheet 2 of 4	W.G. No. S.O. 913C 1-2

OPERATION CODE 760	DESCRIPTION	SET UP CODE 761	RPM / FEED
	Original set up to turn steady rest dia. Chuck small end, set bullcenter in arm end, and indicate O.D. per sketch.		
1	Turn 6.700 dia. steady rest dia, 6" wide, per sketch. TOOL # 1 Valenite LTE-20 (TNMG-544C) 883		250 / .010
2	Remove burrs.		



DB

All dia's to O.D within .02 T.I.R.
All dia's not noted
Surface finish
Denotes stamping location

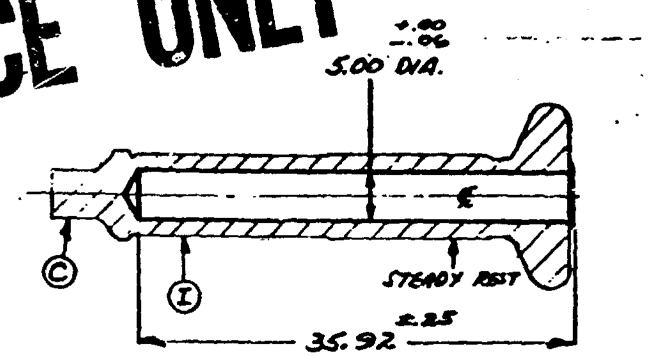
EQUIPMENT Lathe		MATERIAL Aluminum 7079-T6	
WG	SHOP	CUST —	FC# SHOP
DATE 4-14-67	CHKD	APPVD	WG CUST

TABLE VIII

ACCT	Sheet 3 of 4	W.G. No. SO.913C 1-2

OPERATION CODE 770	DESCRIPTION	SET UP CODE 771	RPM / FEED
	Original set up to spade drill. Chuck small end, steady rest near arm end and indicate per sketch.		
1	Drill 5.00 dia. hole 35.92 ±.25 deep. TOOL # 1 5" Dia. Spade Drill		145 / .012
2	Remove burrs		

REFERENCE ONLY



DB

All dia's ⊙ to O.D within .06 T.I.R.
All dia's not noted
Surface finish
Denotes stamping location

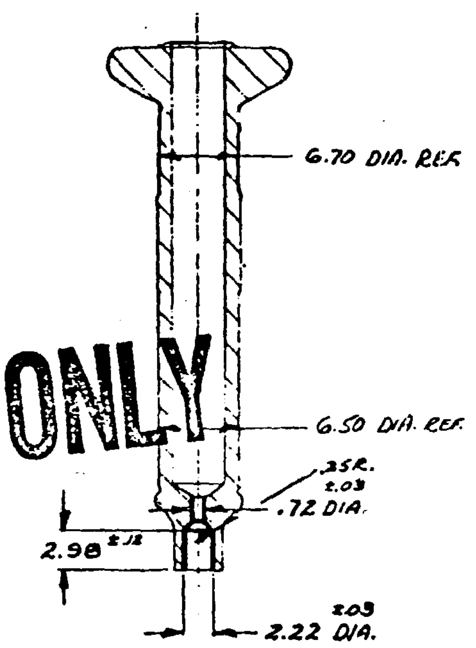
EQUIPMENT Hollow Bore Lathe			MATERIAL Aluminum 7079-T6
WG —	SHOP —	CUST —	FC# SHOP
DATE 4-14-67	CHKD WCJ	APPVD	WG / CUST

Best Available Copy

TABLE IX

RCCT	Sheet 4 of 4	W.G. No. S.O. 9130 1-2

OPERATION CODE 780	DESCRIPTION	SET UP CODE 781	RPM / FEED
	Original set up to drill small end. Set part in vee blocks, level and line up per layout, and strap over vee blocks.		
1	Center drill small end. TOOL # 1 # 8 Center Drill		450 Hand
2	Drill 2 7/32" dia. hole 2.98 ±.12 deep. TOOL # 2 2 7/32" Dia. Drill w/.25 radius		350 .012
3	Drill 23/32 dia. hole through TOOL # 3 23/32" Dia. Drill		1000 .010
4	Remove burrs		



DB

All dia's ⊙ to O.D. within .06 T.I.R.
All dia's not noted
Surface finish
Denotes stamping location

EQUIPMENT 4" G & L		MATERIAL Aluminum 7079-T6	
WG —	SHOP	CUST —	FC# SHOP
DATE 4-15-67	CHKD	APPVD	WG / CUST

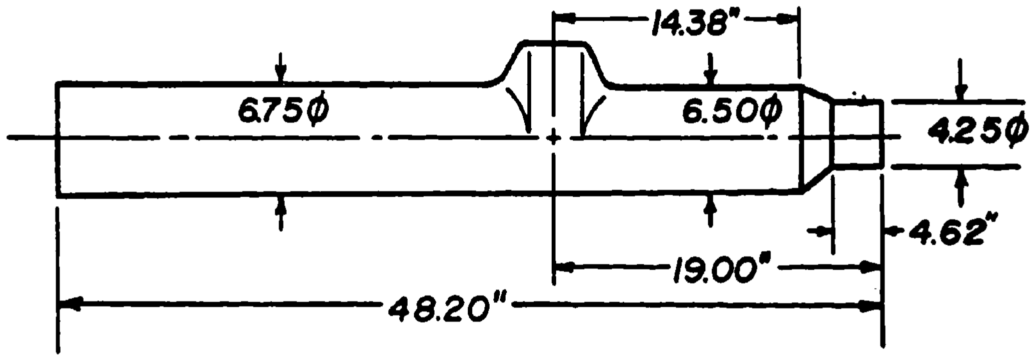
TABLE X

FORGE SHOP DATA SHEET FOR METHOD "C".

ROLLING OPERATION.

Furnace Temperature: 750° F.

Lubrication: White and Bagley forging compound (swabbed on dies only).



Serial Number	4.25	14.38	4.62	19.00	48.20
12.	4.12	15.50	7.68	23.00	52.50
13.	3.95	14.38	5.20	19.58	49.20
14.	4.25	15.58	5.62	21.50	48.95
15.	4.31	14.63	6.12	20.50	48.20

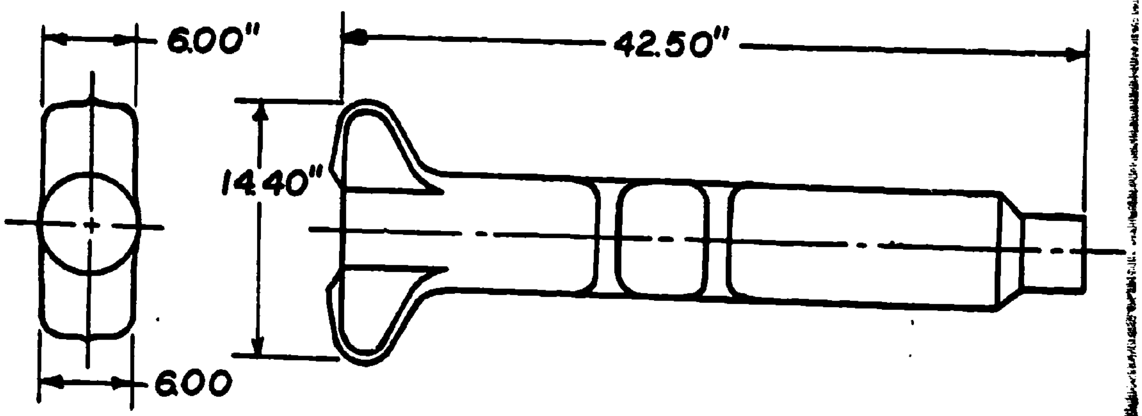
TABLE XI

FORGE SHOP DATA SHEET FOR METHOD "C"

NUMBER 3 UPSET OPERATION.

Furnace Temperature: 750°F.

Lubrication: White and Bagley forging compound.



Serial Number	42.50	6.00	6.00	14.40
12.	47.00	6.00	6.02	14.12
13.	46.00	6.00	6.02	14.25
14.	44.50	5.96	5.96	14.40
15.	44.00	6.00	6.00	14.40

NOTE: Excessive material removed from 4.25 diameter prior to finish forging.

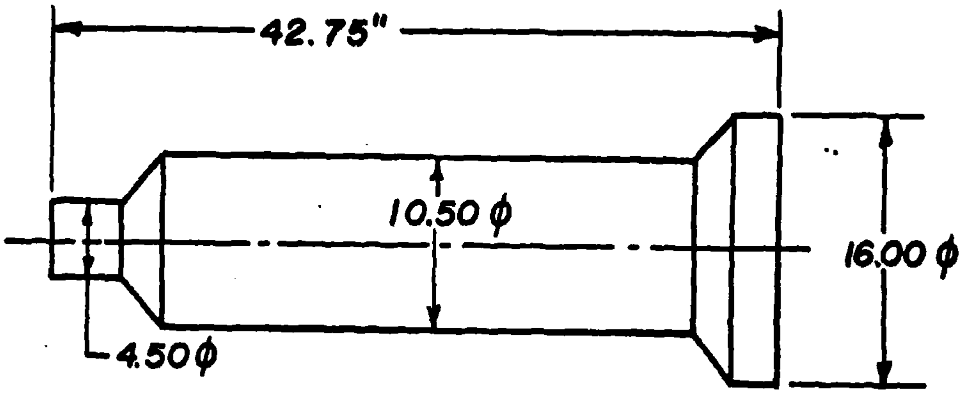
TABLE XII

FORGE SHOP DATA SHEET FOR METHOD "D".

EXTRUDE OPERATION.

Furnace Temperature: 820°F.

Lubrication: White and Bagley forging compound.



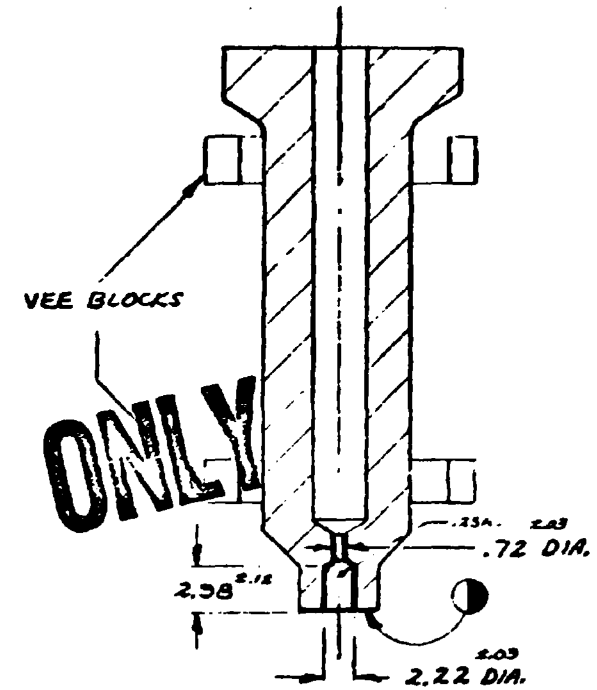
Serial Number	10.50	42.75	Weight
16.	10.52	40.00	290.5 #
17.	10.50	42.75	298.0 #
18.	10.53	42.80	302.5 #
19.	10.52	43.00	303.5 #

TABLE XIII

ROOT | Sheet 1 of 4 | W.G. No. S.O. 91 3

OPERATION CODE 770	DESCRIPTION	SET UP CODE 771	RPM / FEED
	Original set up to face small end, center drill and drill. Set part on vee blocks, line up per layout, and strap over vee blocks.		
1	Set spindle on center per layout, and mark vernier readings.		—
2	Face end of part per layout line. TOOL # 1 6" dia. Face Mill (Pos. Pos.)		250 5IPM
3	Set spindle on center per marked vernier readings, and center drill TOOL # 2 # 8 Center Drill		450 Hand
4	Drill 2 7/32" dia. hole 2.98 ±.12 deep. TOOL # 3 2 7/32" dia. Drill with .25 radius		350 .012
5	Drill 23/32" dia. hole through. TOOL # 4 23/32" Dia. Drill.		1000 .010
6	Stamp S.O. No. and Serial No. on end per sketch.		
7	Remove burrs.		

REFERENCE ONLY



All dia's ⊙ to ___ within ___
All not noted ___
Surface finish ___
⊙ Denotes stamping location

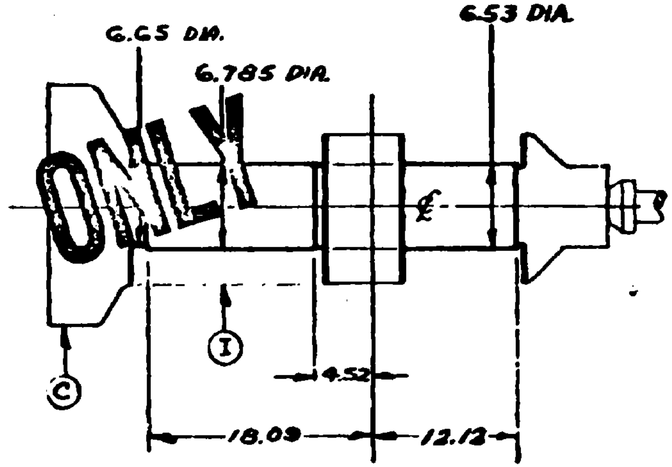
EQUIPMENT 4" G & L			MATERIAL Aluminum 7079-T6
WG —	SHOP	CUST —	FC# SHOP
DATE 3-30-67	CHKD DB	APPVD	WG 0217 / CUST

Worc. Form 722B (Rev. 12/66)

TABLE XIV

ROOT	Sheet 2 of 4	W.G. No. S.O. 91 73

OPERATION CODE 780	DESCRIPTION SET UP CODE 781	RPM / FEED
	Original set up to turn O.D. Chuck flange end and set bullcenter in small end. Line up former per layout. Indicate O.D. near flange.	
1	Turn 6.785 dia. between 4.52 dim. and 18.09 dim. TOOL # 1 Valenite LTE-24(TNMG-666C) 883	600 .015 Rgh .010 Fin
2	Pick up tracing combination from 6.785 dia. and layout, and establish 6.53 dia., using tracer as a guide. TOOL # 1	
3	Pick up tracing combination from 6.785 dia. and layout, and establish contour wherever possible with this tool, using tracer as a guide. TOOL # 2 Carboloy DJPL-85 (DPG-533)	
4	Pick up tracing combination from 6.785 dia. and layout, and establish contour wherever possible with this tool, using tracer as a guide. TOOL # 3 Carboloy DJPR-85 (DPG-533)	
5	Remove burrs.	



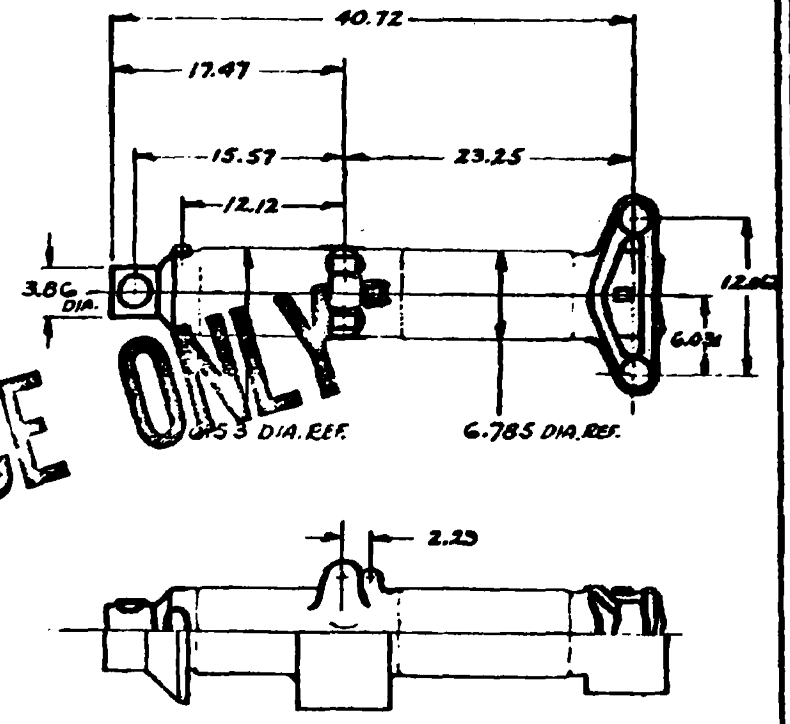
DB

All dia's to each other within .03 T.I.R.
All dim's not noted . Dia's ±.010 Lengths ±.030
Surface finish 150 AA
Denotes stamping location

EQUIPMENT Tracer Lathe		MATERIAL Aluminum 7079-T6	
WG —	SHOP —	CUST —	FC# SHOP
DATE 3-31-67	CHKD DB	APPVD	WG 0217 CUST

TABLE XV

OPERATION CODE		790 DESCRIPTION	SETUP CODE 791	RPM / FEED
	Original set up to machine side # 1. Set fixture on backstops. Set part in fixture, level per layout, and strap. Line up model per layout.			
1	Rough bump part using ½" index.			650
	TOOL # 1 2" dia. Alum. Ball End Mill 3" Long.			5-10 IPM
2	Finish bump part using .200 index.			1200
	TOOL # 2 1" dia. Alum. Ball End Mill 3" Long.			15-25 IPM
3	Remove burrs.			
	NOTE: Leave fixture set up for next operation.			



REFERENCE ONLY

•All Dia's ⊙ to ____ within ____________

All Dim's not noted ____________

Surface Finish ____________

● Denotes - Stamping Location

NOTE:

TIME	1	3	5	7	9
STUDY	2	4	6	8	10

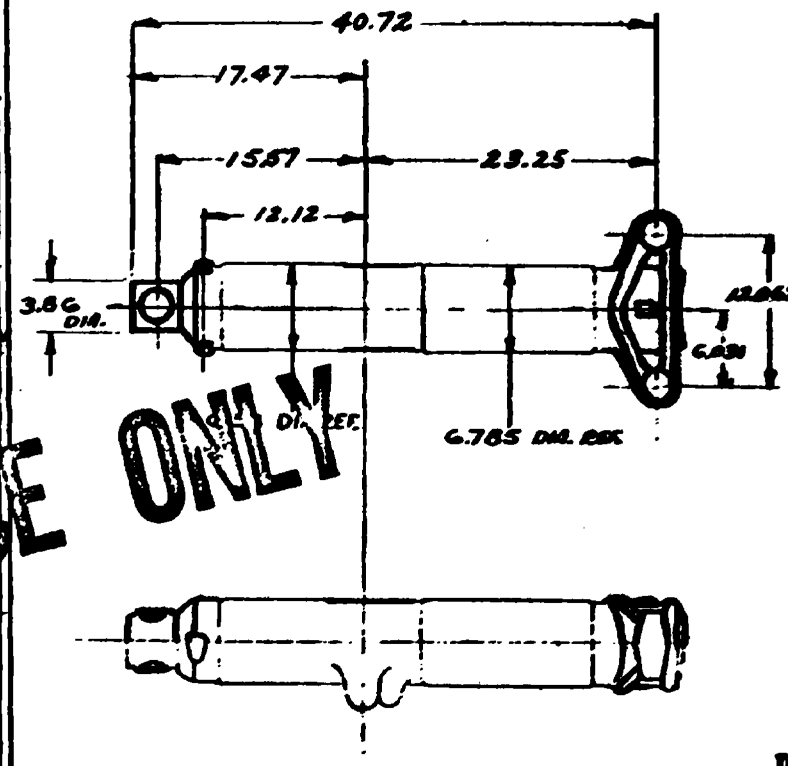
TOTAL	DATE 4-5-67	CHECKED LCC	APPVD.
	WG CHG.	CUST. CHG.	E.O. SHOP
	EQUIP. Keller		MAT'L Aluminum 7079-T6

Machine Process Sheet - Worc. Form 722 A (Rev. 9/62)

ROOT	Sheet 3 of 4	WG No. S.O. 9133

TABLE XVI

OPERATION CODE	800 DESCRIPTION	SETUP CODE 801	RPM / FEED
	Original set up to machine Side # 2. Reverse part in fixture used for side # 1, level to layout, and strap. Remove model for side # 1 and set up model for side # 2. Line up model per layout.		
1	Rough bump part using ½" index.		650
	TOOL # 1 2" dia. Alum. Ball End Mill 3" Long		5-10 IPM
2	Finish bump part using .200 index.		1200
	TOOL # 2 1" dia. Alum. Ball end Mill 3" Long		15-25 IP
3	Remove burrs.		



All Dia's ⊙ to ____ within ____
All Dim's not noted ____
Surface Finish ____
◐ Denotes - Stamping Location

NOTE:

TIME	1	3	5	7	9
STUDY	2	4	6	8	10

TOTAL	DATE 4-5-67	CHECKED WC	APP'VD.
	WG CHG.	CUST. CHG.	F.O. SHOP
	EQUIP. Keller	MAT'L. Aluminum 7079-T6	

Machine-Process Sheet - Worc. Form 722 A (Rev. 9/62) | ROOT | Sheet 4 of 4 | WG No. S.O. 9133

TABLE XVII

STRESS CORROSION DATA SHEET FOR MCG 282

Initiated August 28, 1967 - Terminated September 27, 1967 (1)

(Etched 30 sec. in 5% NaOH at 180°F, desmutted in 50% HNO_3
Failure time in days unless noted.) (2)

Sample Number	Parting Line Stressed	Stress Ksi	#30 Conventional	#31 Regular Cogging	#32 Offset Cogging	#33 Extrusion
1R	No (60°)	30	29	OK	13	OK
2R	No "	30	14	OK	15	OK
3RA	No	45	7	3	7	OK
4RA	No	45	6	2	7	OK
5RB	Yes	15	OK	OK	OK	OK
6RA	No	30	16	13	26	OK
7RB	Yes	15	OK	OK	OK	OK
8RD	Yes	30	9	10	13	OK
9RA	No	15	OK	OK	OK	OK
10RC	No	30	11	7	10	OK
11RB	Yes	45	6	1	2	OK
12RD	Yes	30	10	7	12	OK
13RA	No	45	6	17 hrs.	2	OK
14RC	No	30	12	9	11	OK
15RB	Yes	45	6	1	1	OK
16RD	Yes	15	OK	OK	OK	OK
17RA	No	15	OK	OK	OK	OK
18RC	No	15	OK	OK	OK	OK
19RB	Yes	30	10	9	11	OK
20RD	Yes	45	2	2	2	OK
22RC	No	45	4	2	3	OK
27RB	Yes	30	30	19	9	OK
28RD	Yes	45	6	1	2	OK
29RA	No	30	11	OK	OK	OK
30RC	No	15	OK	OK	OK	OK
31RB	Yes	15	OK	OK	OK	OK
32RD	Yes	15	OK	OK	OK	OK
33RA	No	15	OK	OK	OK	OK
34RC	No	45	9	3	8	OK
35RB	Yes	45	3	2	9	OK
36RD	Yes	30	11	13	16	OK

TABLE XVII (continued)

Sample Number	Parting Line Stressed	Stress Ksi	#30 Conventional	#31 Regular Cogging	#32 Offset Cogging	#33 Extrusion
37RA	No	45	12	6	8	OK
38RC	No	30	OK	16	OK	OK
39RA	No	45	20	6	14	26

(1) 30 day - 3.5% NaCl alternate immersion (10 min. wet/50 min. dry each hour). Solution temperature was 75F, R.H. during drying was 40%. Air temperature was 80F.

(2) Samples examined daily at 10X and removed if one or more cracks detected or if completely fractured. OK-designates no failure in 30 day test.

TABLE XVIII

STRESS CORROSION DATA SHEET FOR MCG 282

Initiated September 13, 1967 - Terminated October 13, 1967 (1)

(Etched 30 seconds in 5% NaOH @ 180°F, desmutted in 50% HNO_3
Failure time in days.) (2)

6" O.D. C-rings @ 30,000 psi - Stressed area 90° from parting line.

Sample Number	#30 Conventional	#31 Regular Cogging	#32 Offset Cogging	#33 Extrusion
21 RA	14	12	12	OK
23 RA	15	12	16	OK
24 RA	OK	12	13	OK
25 RA	OK	OK	30	OK
26 RC	28	OK	12	OK

Stress Corrosion Rounds

Sample Number	Stress Ksi	#30 Conventional	#31 Regular Cogging	#32 Offset Cogging	#33 Extrusion
40	30	OK	OK	OK	OK
41	45	OK	OK	OK	OK
42	45	OK	OK	OK	OK
43	45	6	12	30	OK
44	30	OK	OK	OK	OK
45	30	OK	OK	OK	OK
46	30	OK	OK	OK	OK
47	45	OK	OK	OK	OK
48	45	OK	OK	7	OK
49	45	OK	OK	6	12
50	45	26	16	19	OK
51	30	OK	OK	OK	12
					9

(1) 30 day - 3.5% NaCl alternate immersion (10 min. wet/50 min. dry each hour). Solution temperature was 75F, R.H. during drying was 40%. Air temperature was 80F.

(2) Samples examined daily at 10X and removed if one or more cracks detected or if completely fractured. OK-designated no failure in 30 day test.

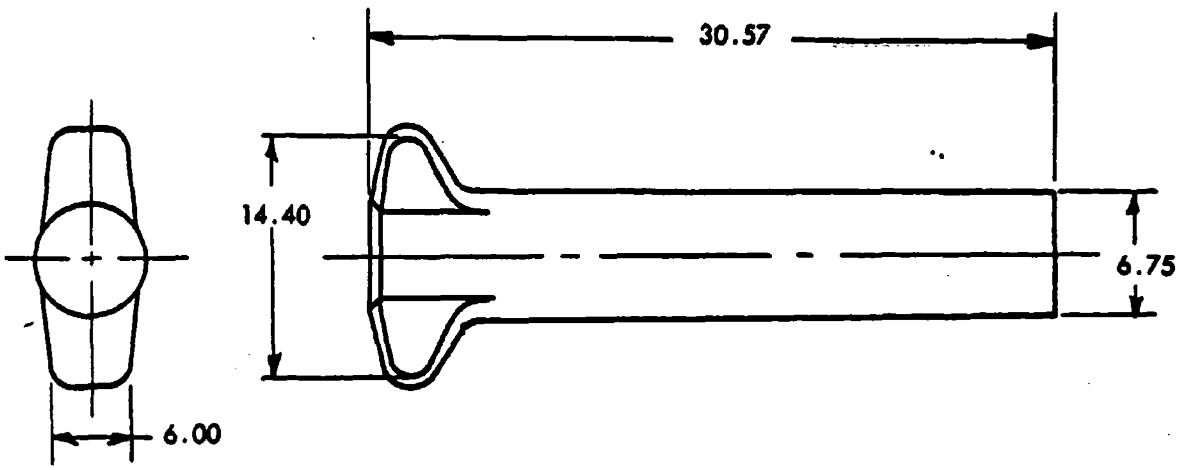
TABLE XIX

FORGE SHOP DATA SHEET

NUMBER I UPSET OPERATION

FURNACE TEMPERATURE: 750°F

LUBRICATION: White and Bagley forging compound



Serial Number	30.57	6.00	6.00	14.40	6.75
1	31.00	5.95	5.95	13.78	6.70
2	30.38	6.00	6.00	14.38	6.74
8	30.50	6.00	6.00	14.20	6.76
9	31.12	6.09	6.10	14.15	6.82

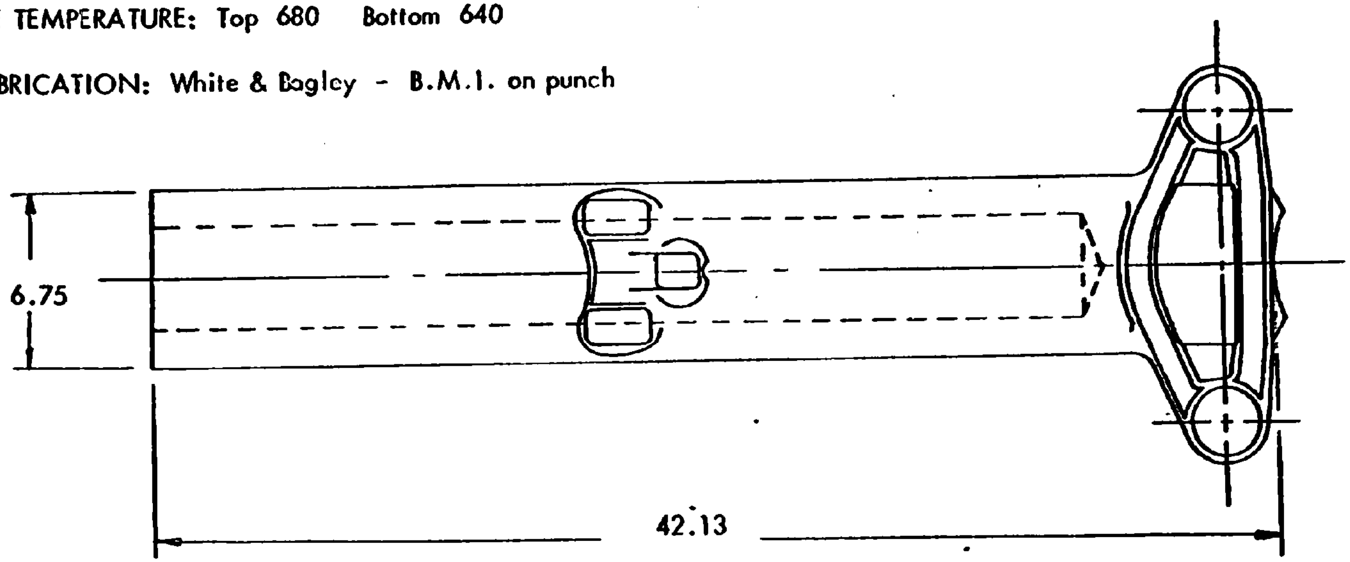
TABLE XX

FORGE SHOP DATA SHEET

FURNACE TEMPERATURE: 820°F

DIE TEMPERATURE: Top 680 Bottom 640

LUBRICATION: White & Bagley - B.M.I. on punch



Serial Number	6.75	42.13	4.00	Concentricity
2	6.78	42.88	4.00	.01 - .07
8	6.75	42.50	4.00	.02 - .04
9	6.75	42.38	4.00	.02 - .05

THESE READINGS TAKEN HOT AT THE PRESS

TABLE XXI

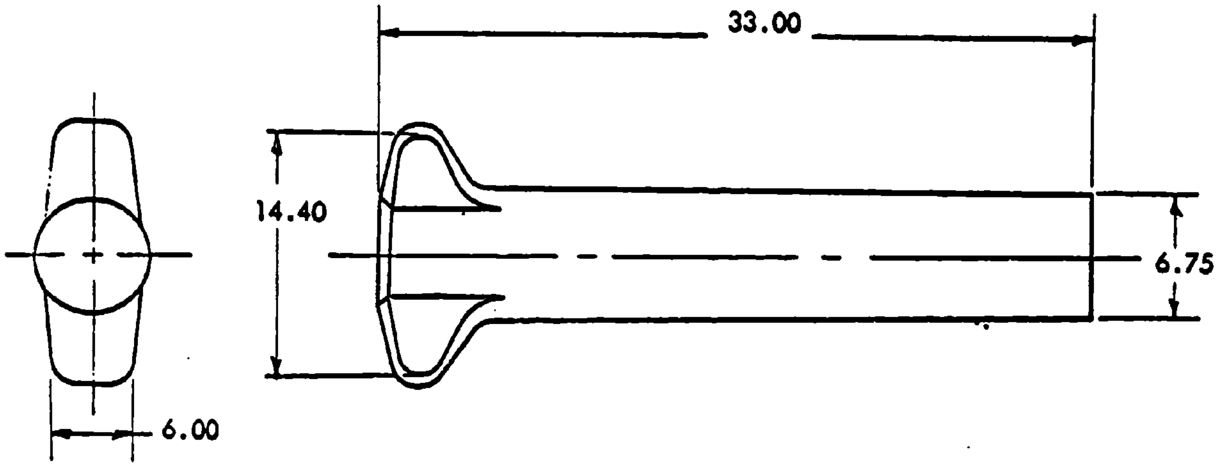
FORGE SHOP DATA SHEET

NUMBER 1 UPSET OPERATION

FURNACE TEMPERATURE: 750°F

LUBRICATION: White & Bagley Forging Compound

DIE TEMPERATURE: 600°F Top and Bottom



Serial Number	33.00	6.00	14.40	6.75
*3	35.50	5.95	12.78	6.70
4	33.00	6.10	14.40	6.76
10	33.38	6.00	14.38	6.74
11	33.50	6.00	14.40	6.75

*Piece number 3 shifted in die (grippers failed). Upset stroke only partially completed, unable to restrike.

TABLE XXII

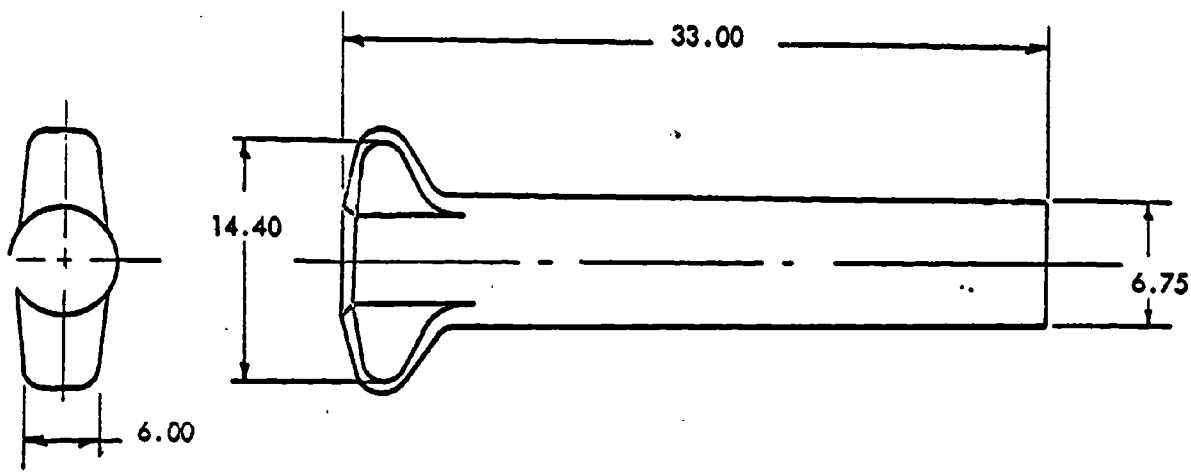
FORGE SHOP DATA SHEET

NUMBER 1 UPSET OPERATION

FURNACE TEMPERATURE: 750°F

LUBRICATION: White & Bagley Forging Compound

DIE TEMPERATURE: 800°F Top and Bottom

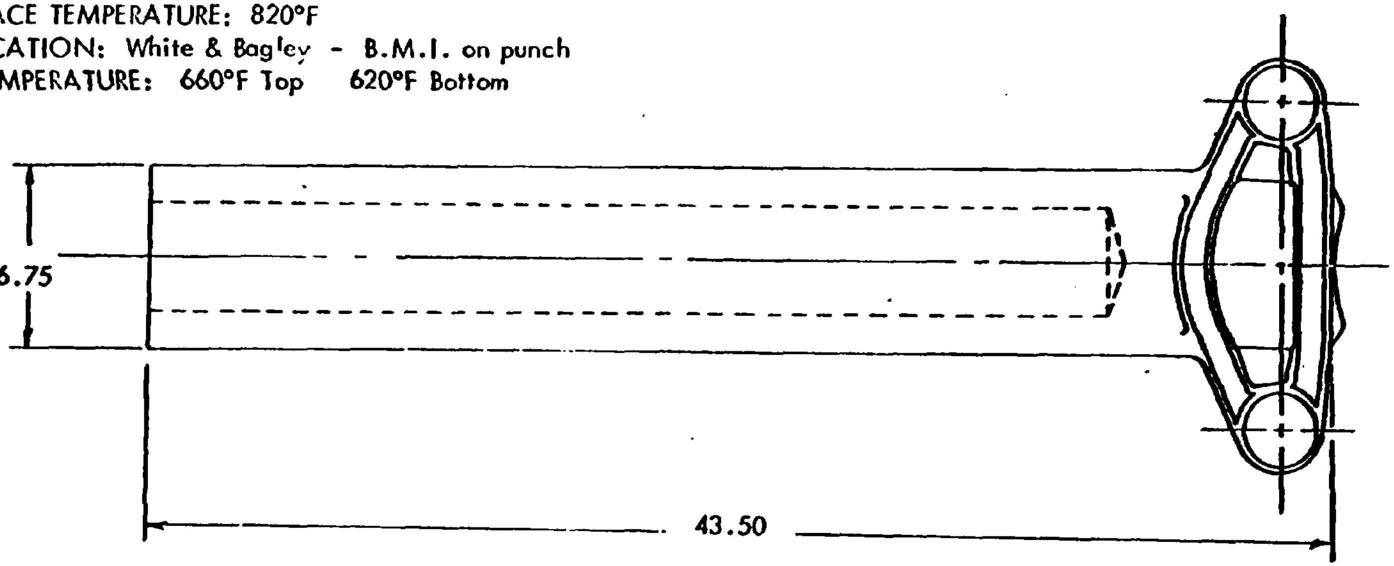


Serial Number	33.00	6.00	14.40	6.75
5	32.50	6.00	14.40	6.73
6	33.38	6.00	13.38	6.75
7	33.25	6.10	14.40	6.76
12	33.50	6.09	13.37	6.74
13	33.25	6.00	13.39	6.75
14	33.38	6.13	14.40	6.75

TABLE XXIII

FORGE SHOP DATA SHEET

BACK EXTRUSION OPERATION
FURNACE TEMPERATURE: 820°F
LUBRICATION: White & Bagley - B.M.I. on punch
DIE TEMPERATURE: 660°F Top 620°F Bottom

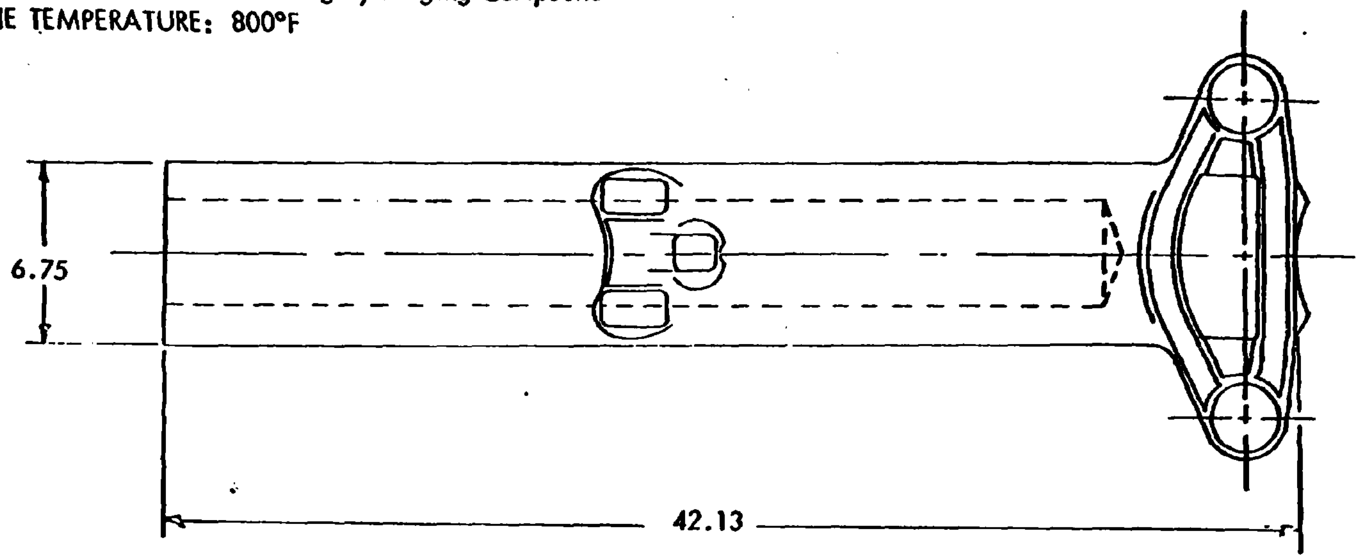


Serial Number	43.50	6.75
3	43.50	6.75
5	43.50	6.75
6	42.50	6.76
7	43.50	6.74
11	43.75	6.75
12	43.50	6.75
13	43.00	6.73
14	44.00	6.75

TABLE XXIV

FORGE SHOP DATA SHEET

UPSET OPERATION
FURNACE TEMPERATURE: 820°F
LUBRICATION: White & Bagley Forging Compound
DIE TEMPERATURE: 800°F



Serial Number	42.13	6.75	Concentricity
5	41.25	6.95	
11	42.25	6.95	.03 - .00
13	42.25	6.93	.09 - .01
14	42.00	6.95	.02 - .05

THESE READINGS TAKEN HOT AT THE PRESS

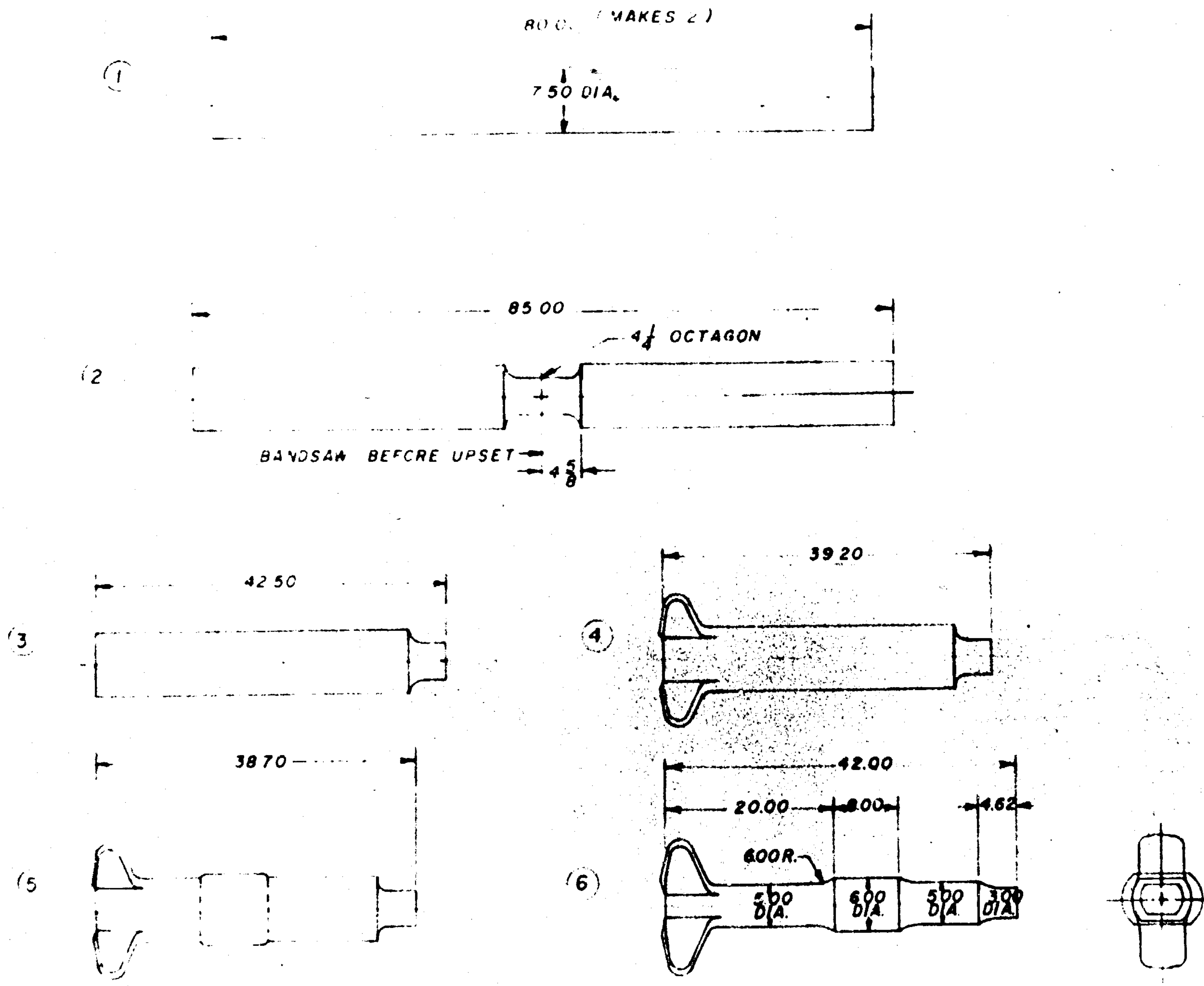


FIGURE 1 - OPERATIONAL SEQUENCE - CONVENTIONAL METHOD

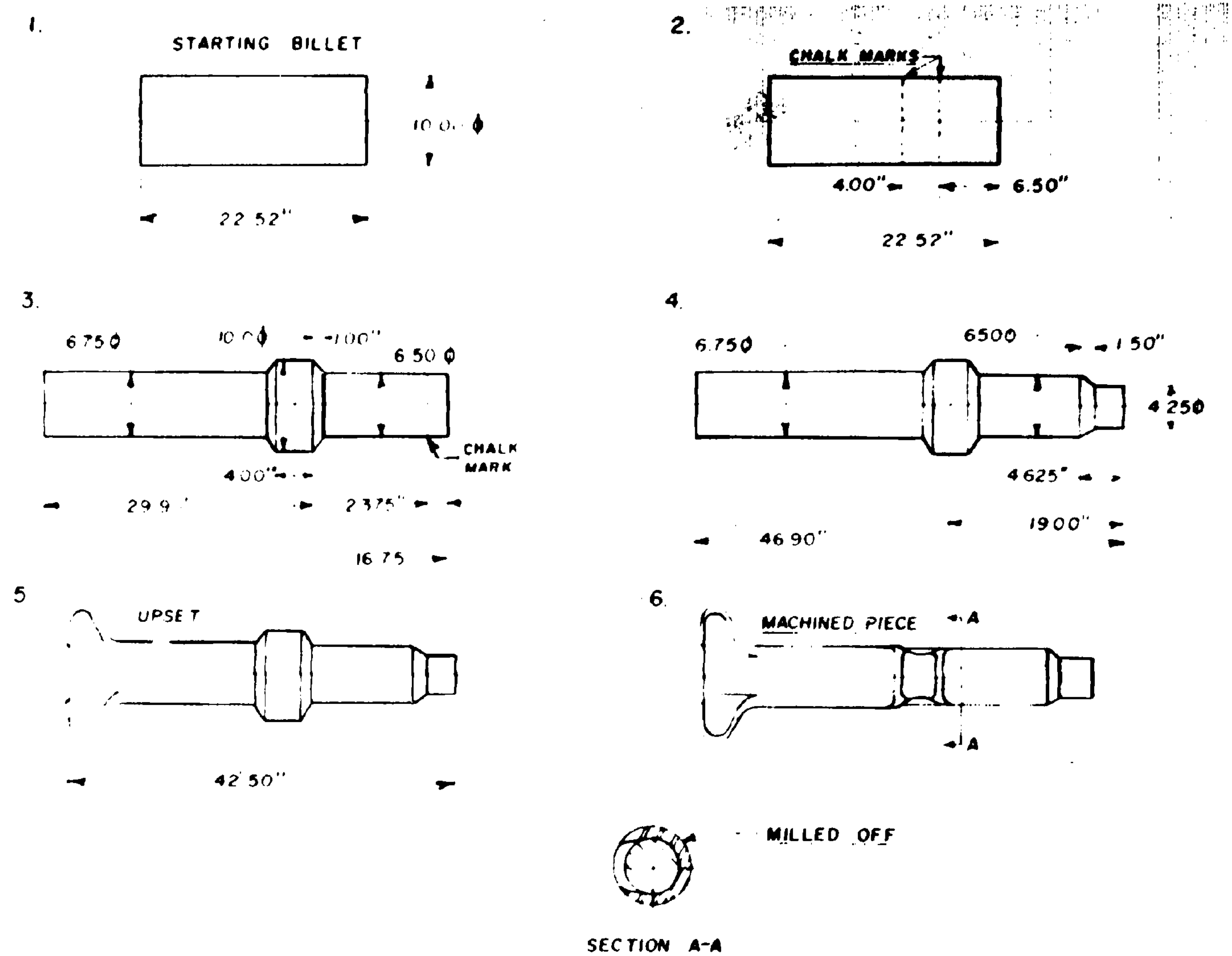


FIGURE 2 - Operational Sequence - Regular Cog

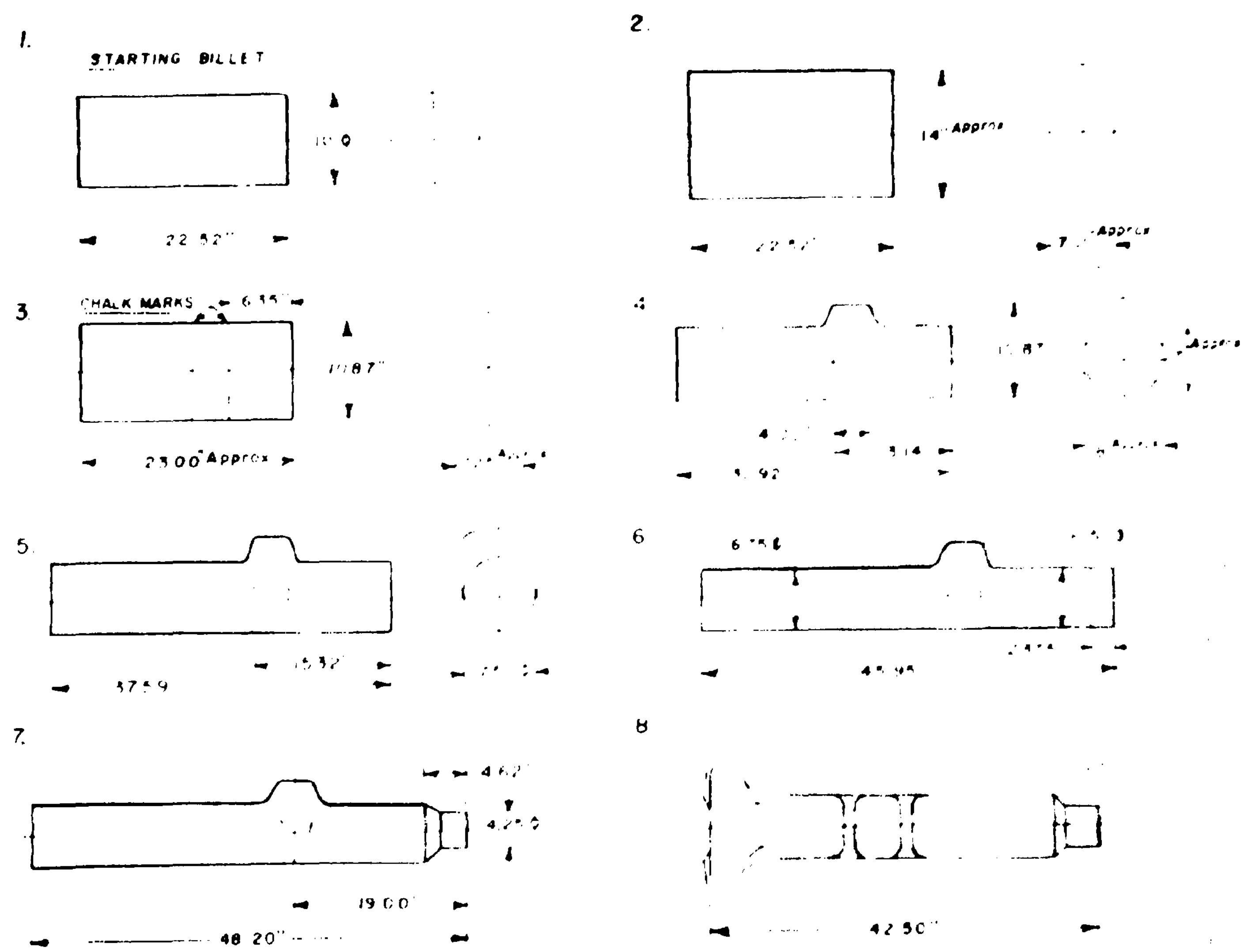


FIGURE 3 - Operational Sequence - Offset Cog

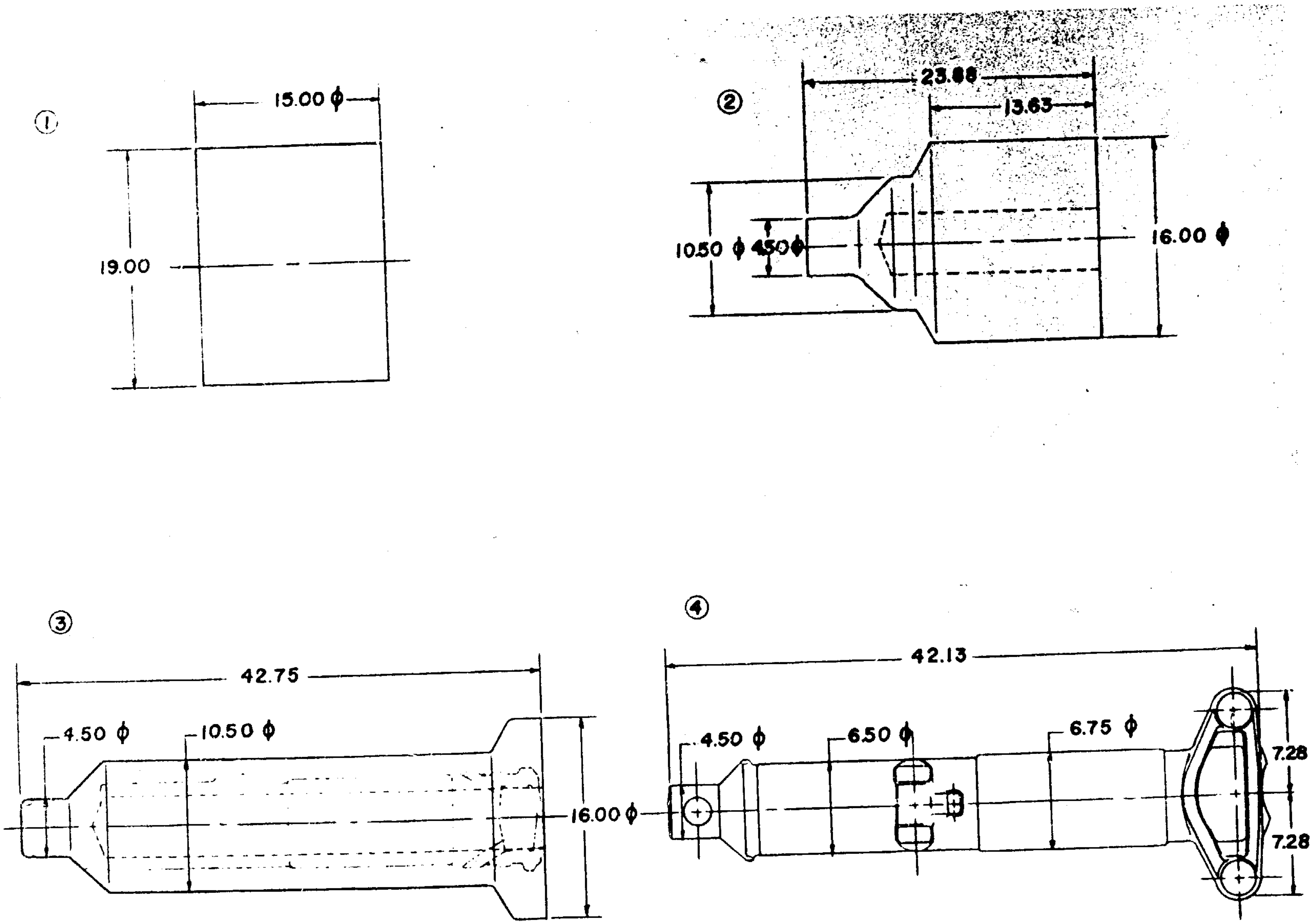


FIGURE 4 - OPERATIONAL EXTRUSION SEQUENCE TECHNIQUE

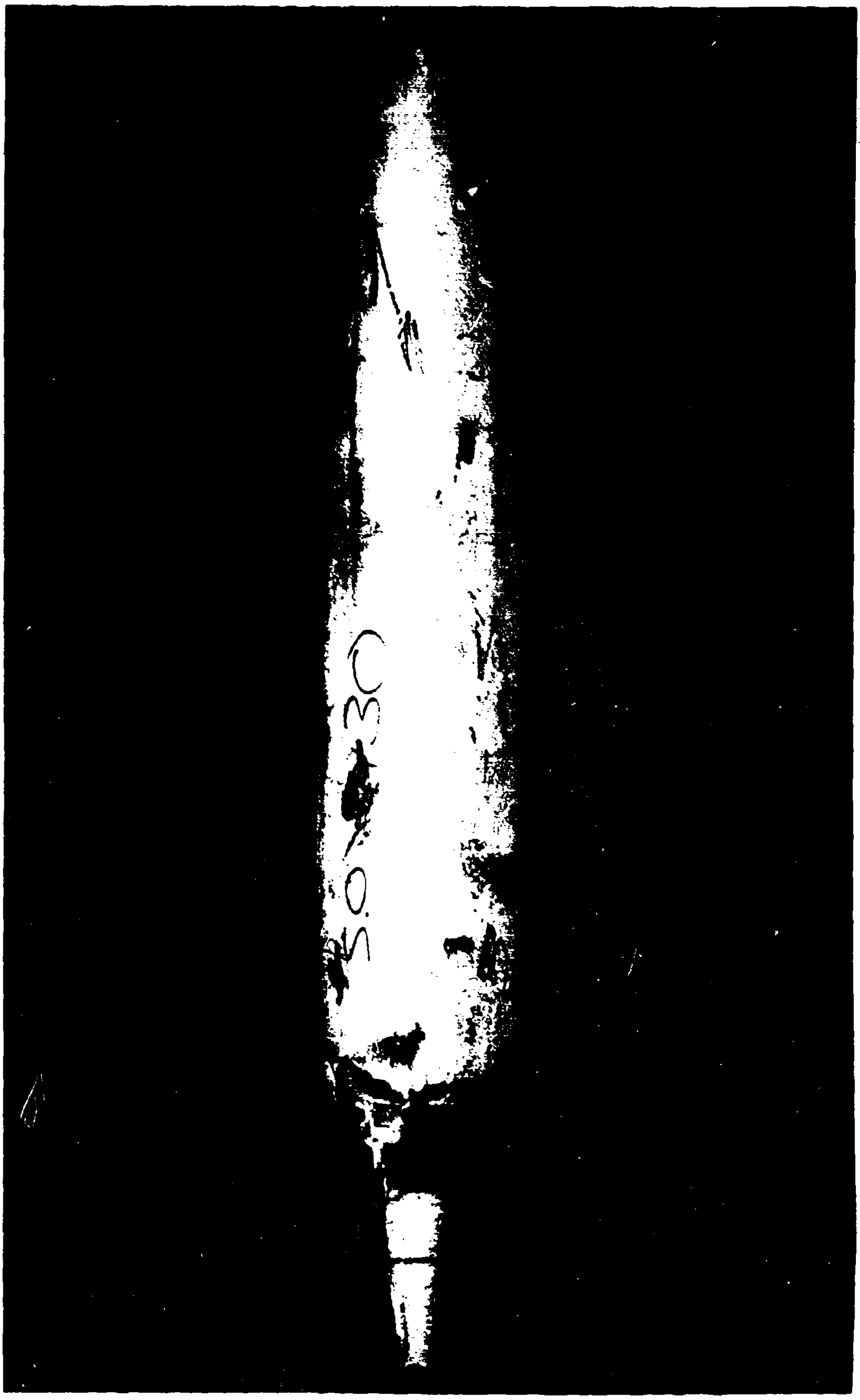


FIGURE 5 - Method "A" Drawn Piece

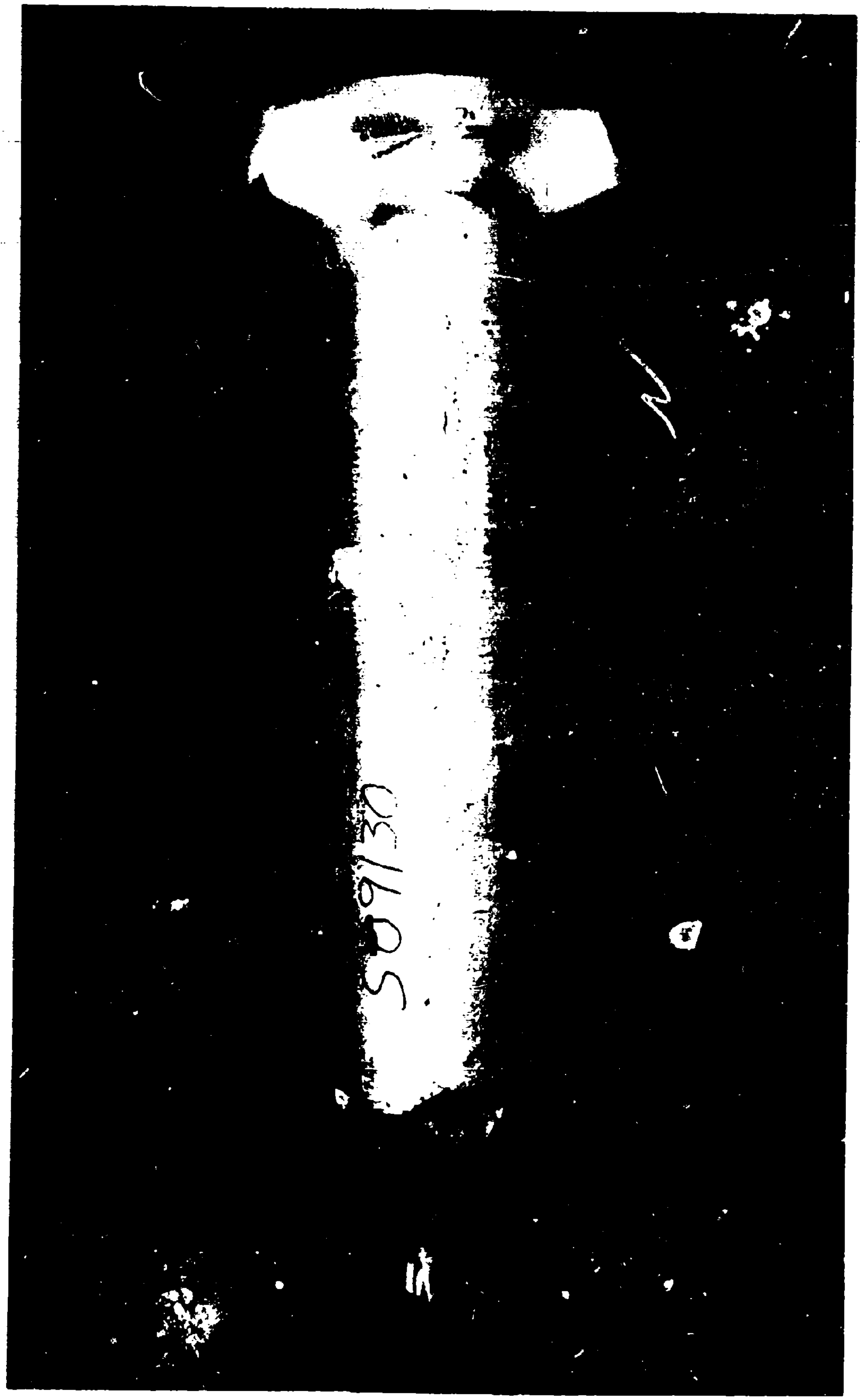


FIGURE 6 - Method "A" No. 1 Upset Piece

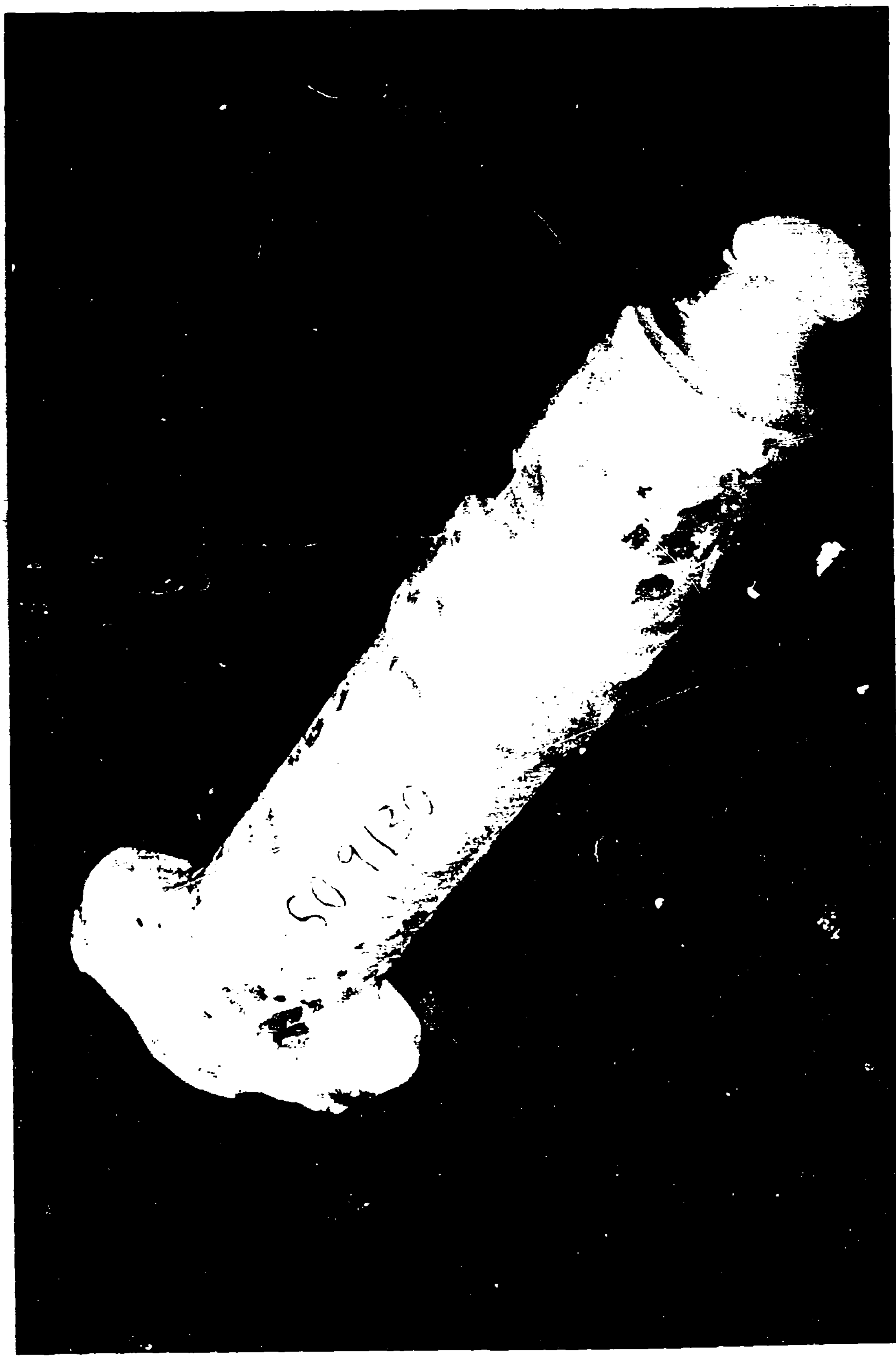


FIGURE 7 - Method "A" No. 2 Upset Piece

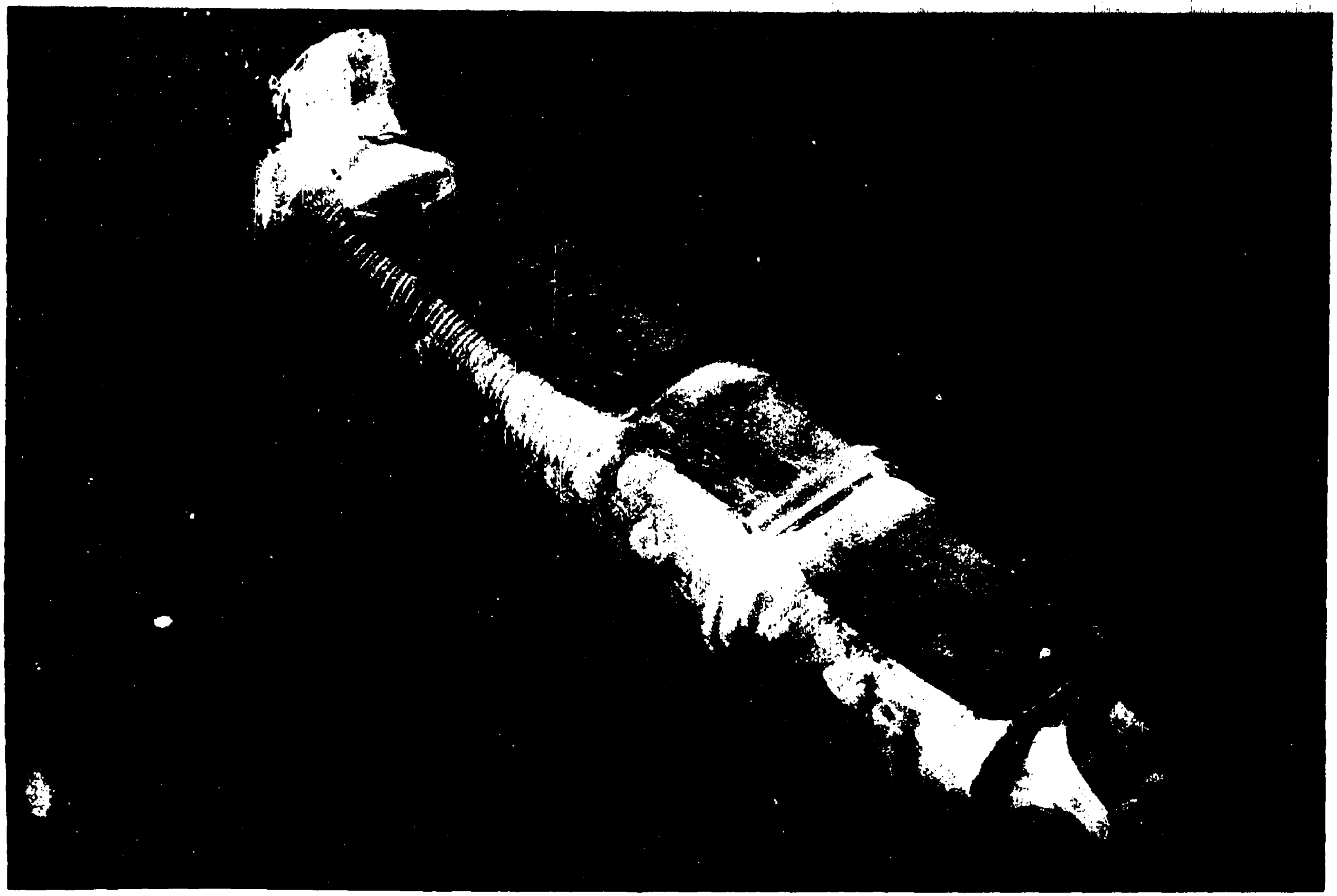


FIGURE 8 - Method "A" Flattend Piece

FIGURE 9 Method "A" Finish Forged Piece

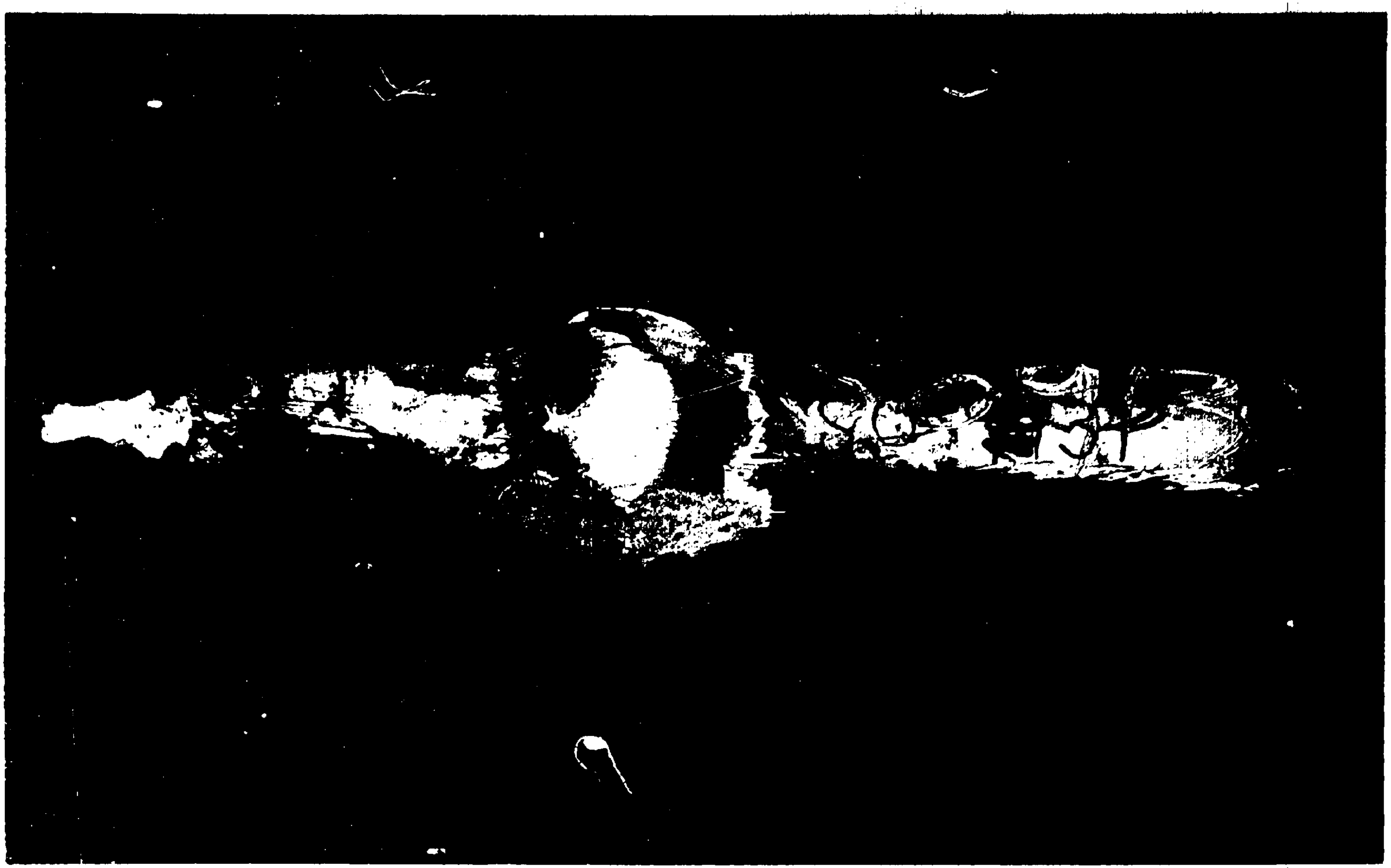


FIGURE 10 Method "B" Cogged Piece

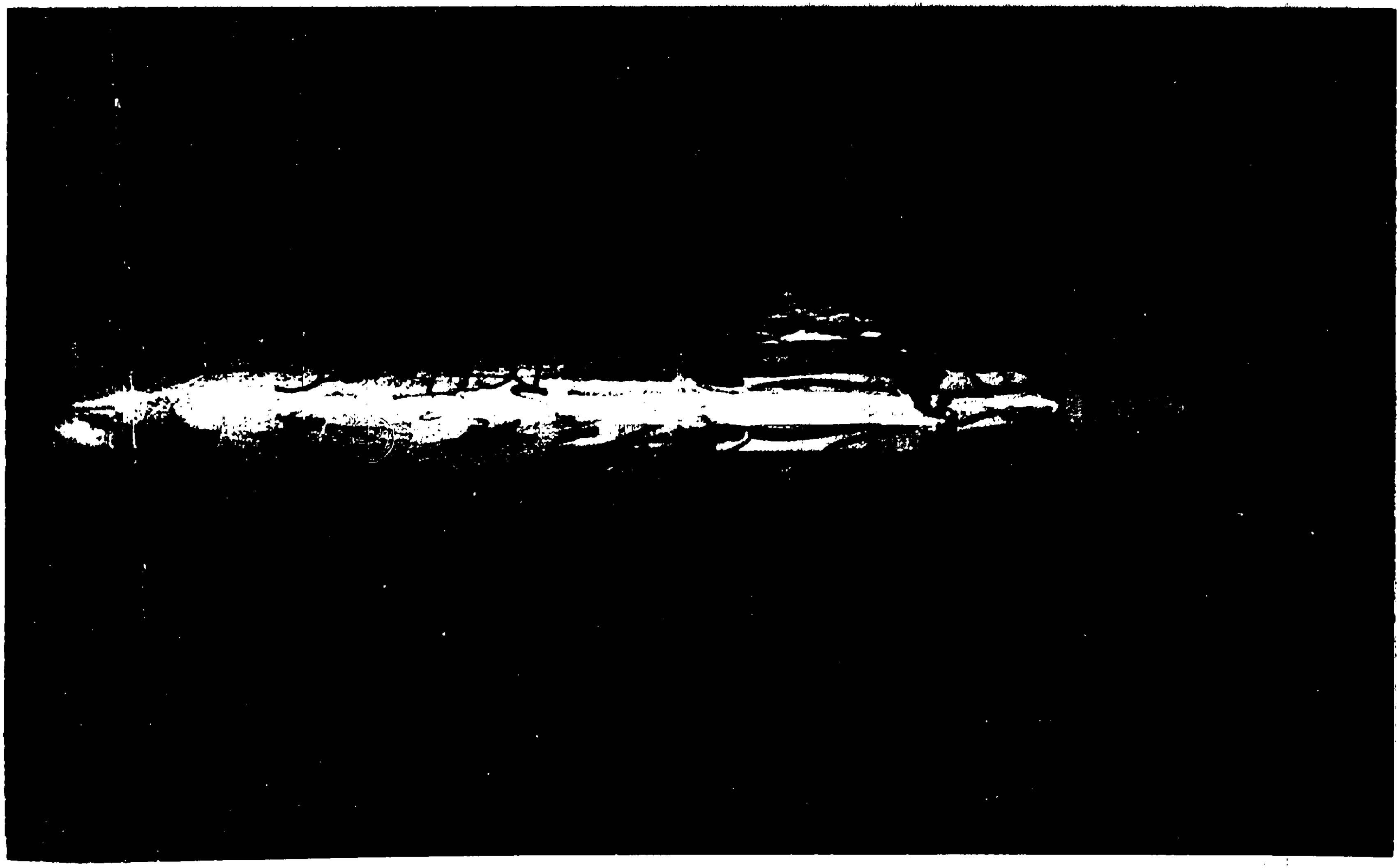


FIGURE 11 Method "B" - Cogged Piece After Machining Away a Portion of the Central Boss Area

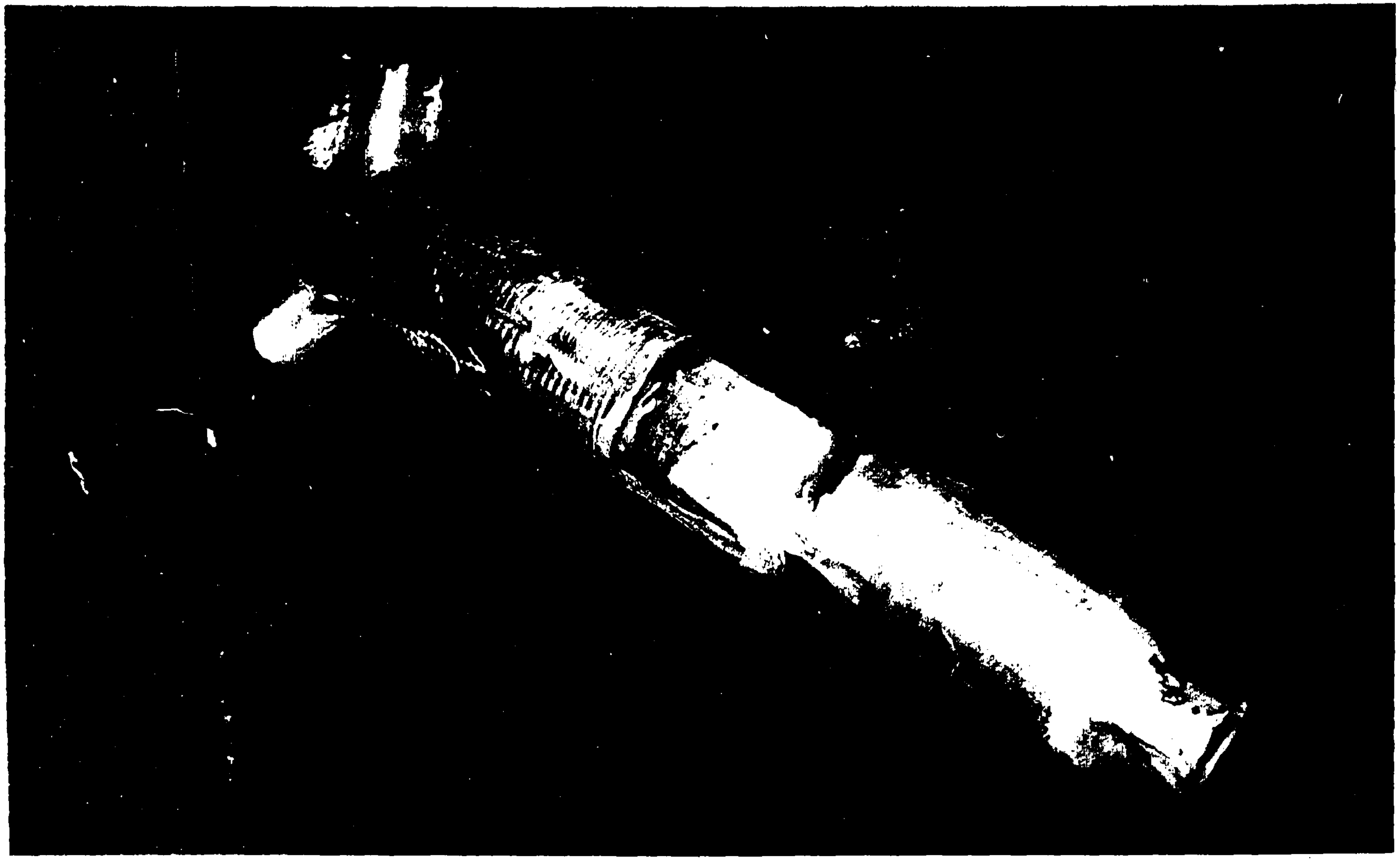


FIGURE 12 Method "B" No. 3 Upset

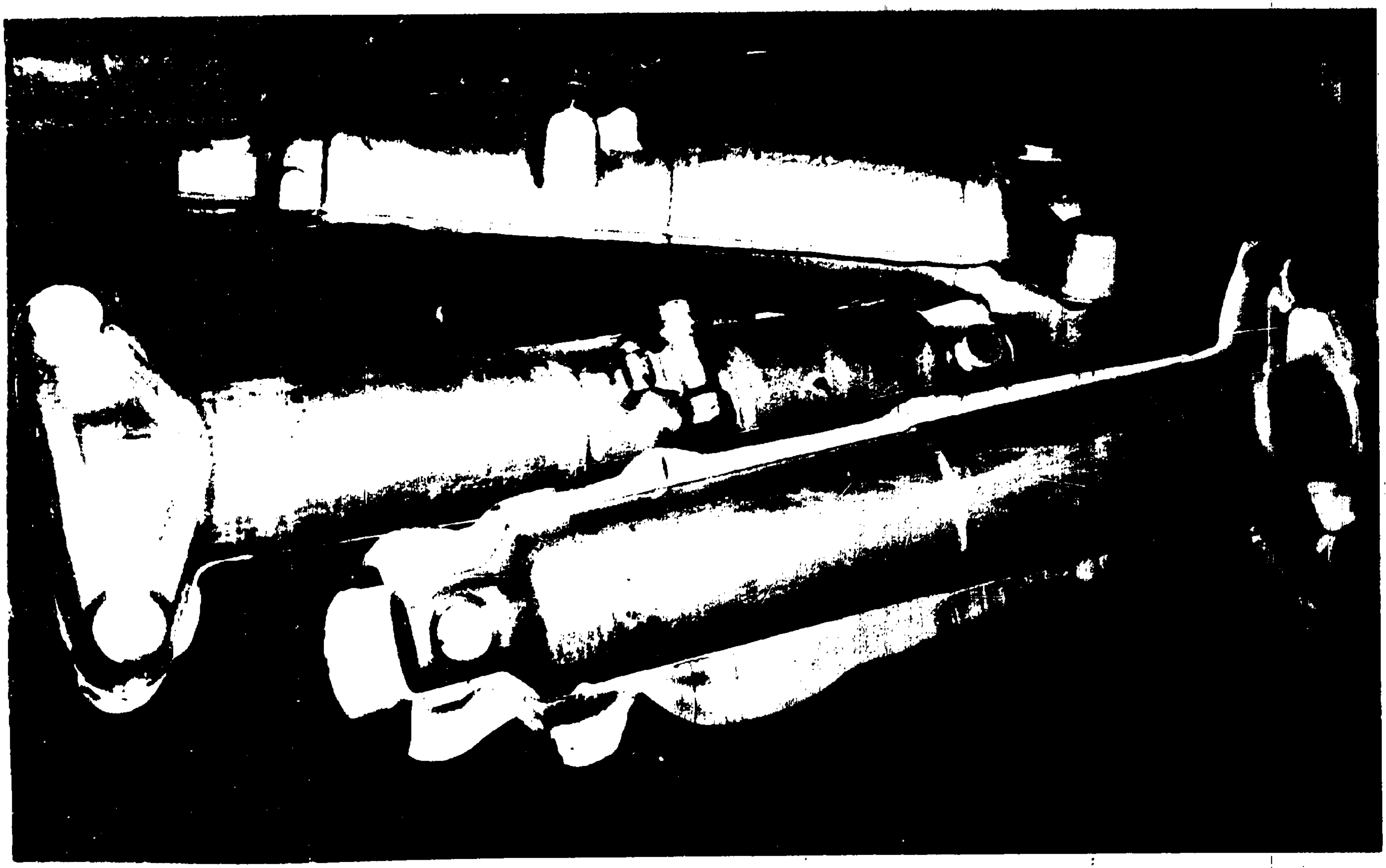


FIGURE 13 Method "B" Finished Forged Pieces

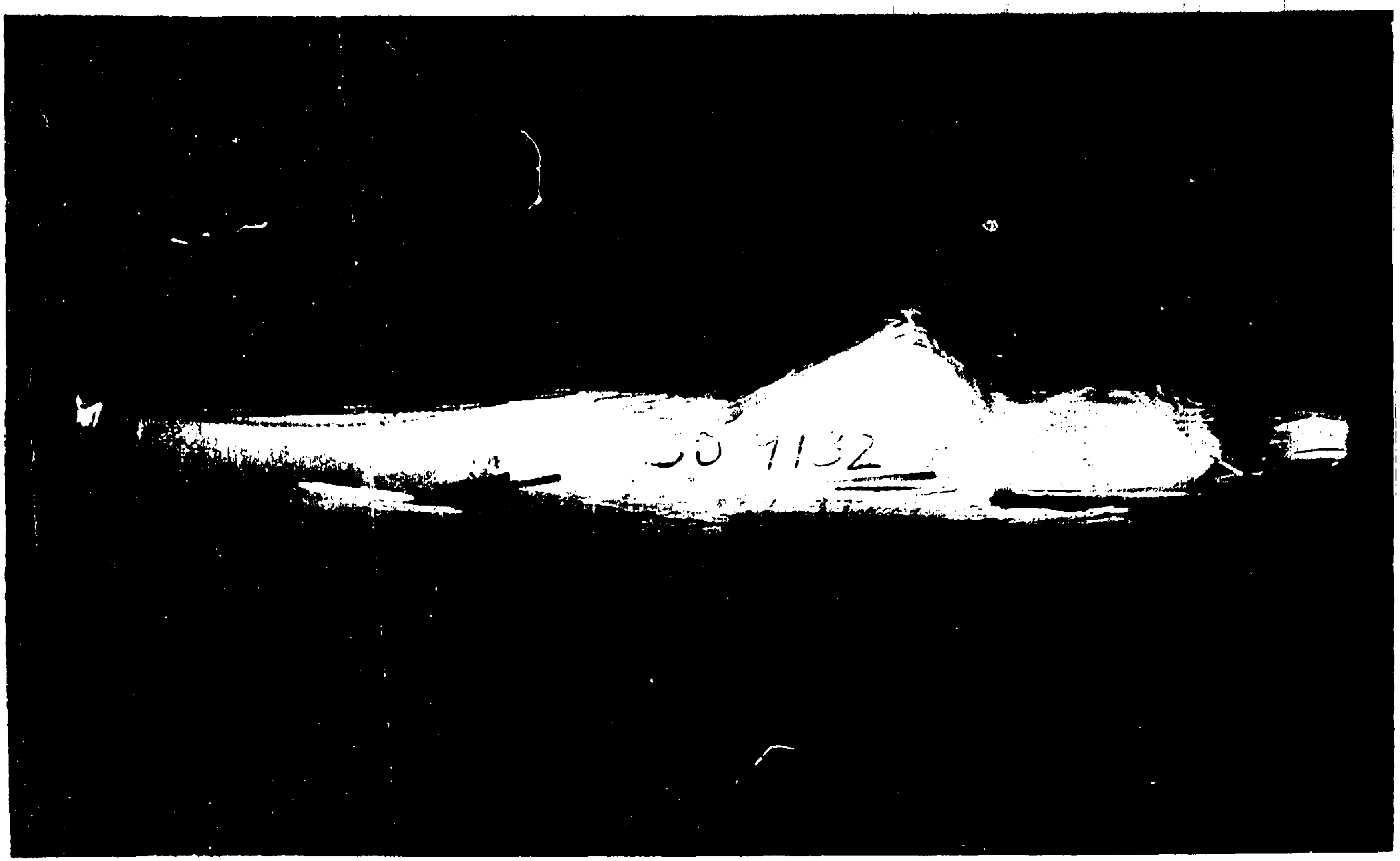
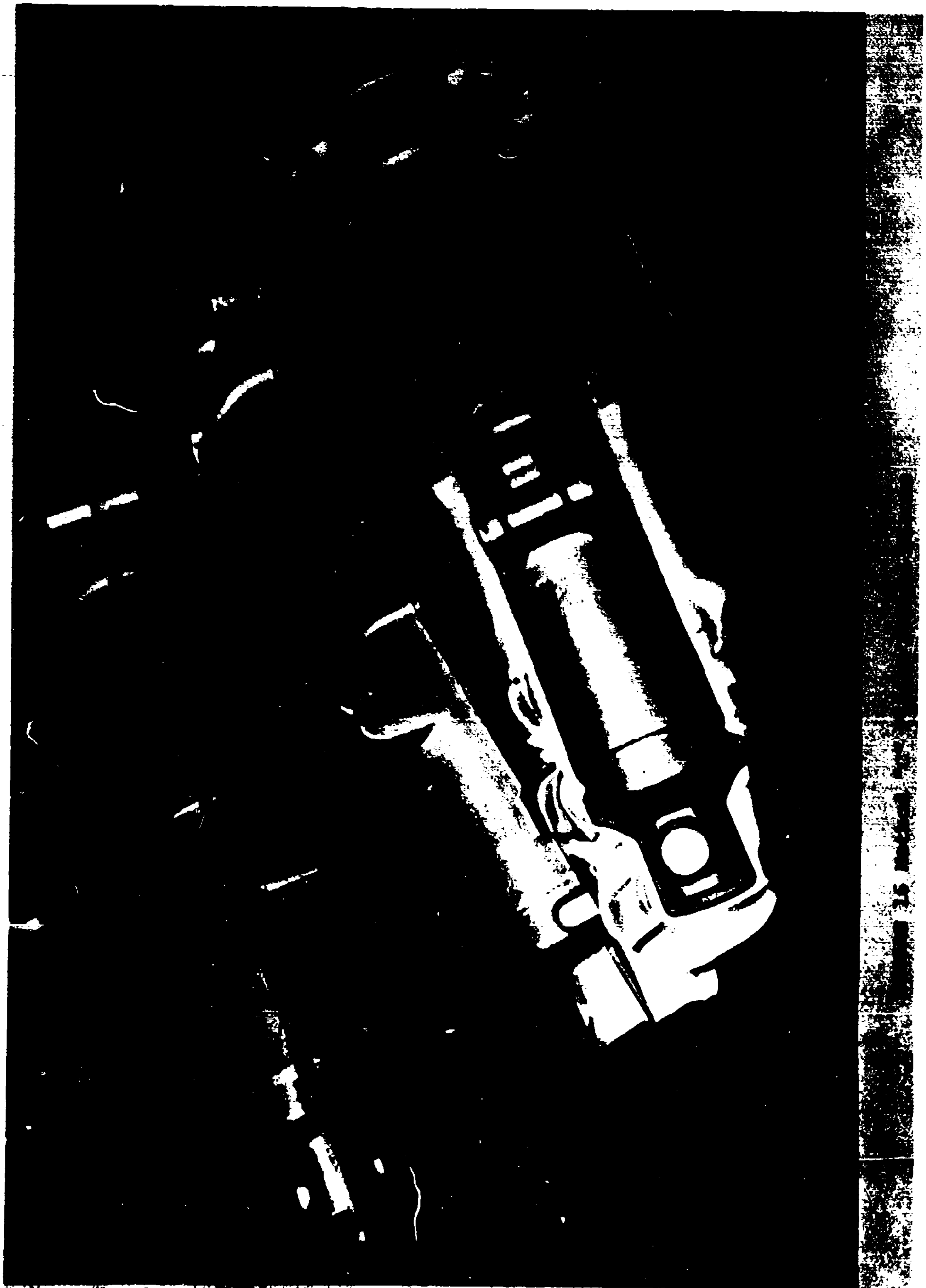
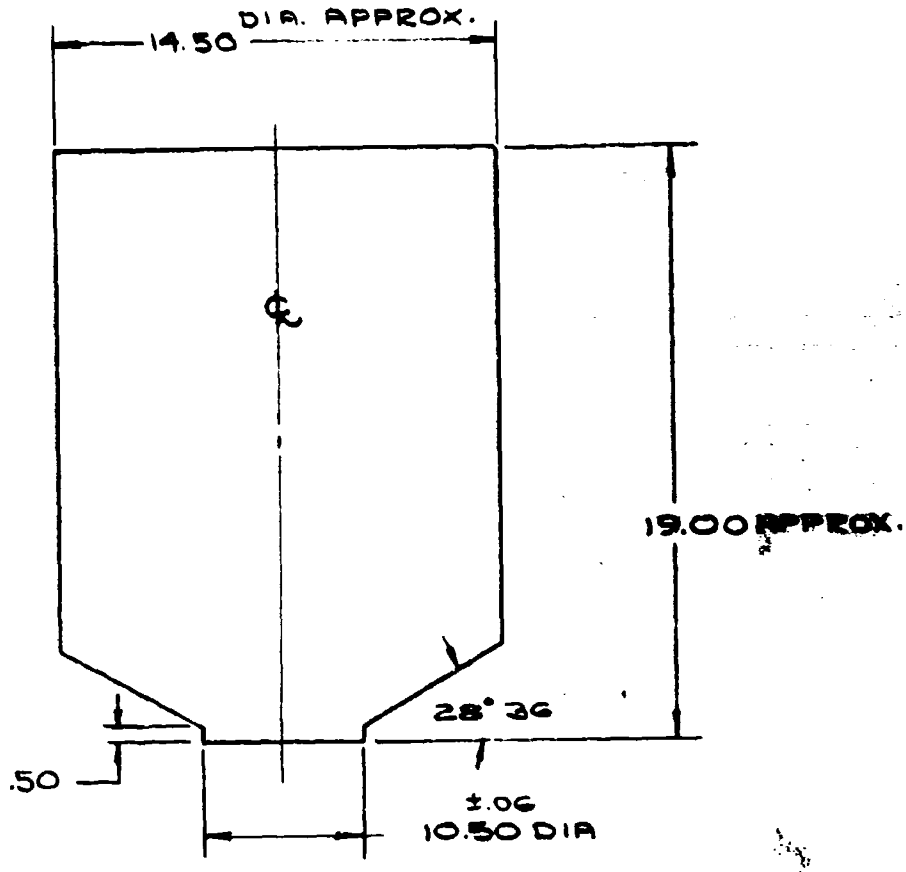


FIGURE 14 Method "C" Offset Cogged Piece

FIGURE 15 Method "C" No. 3 Upset Piece





MACHINED PIECE METHOD "D"

FIGURE 17

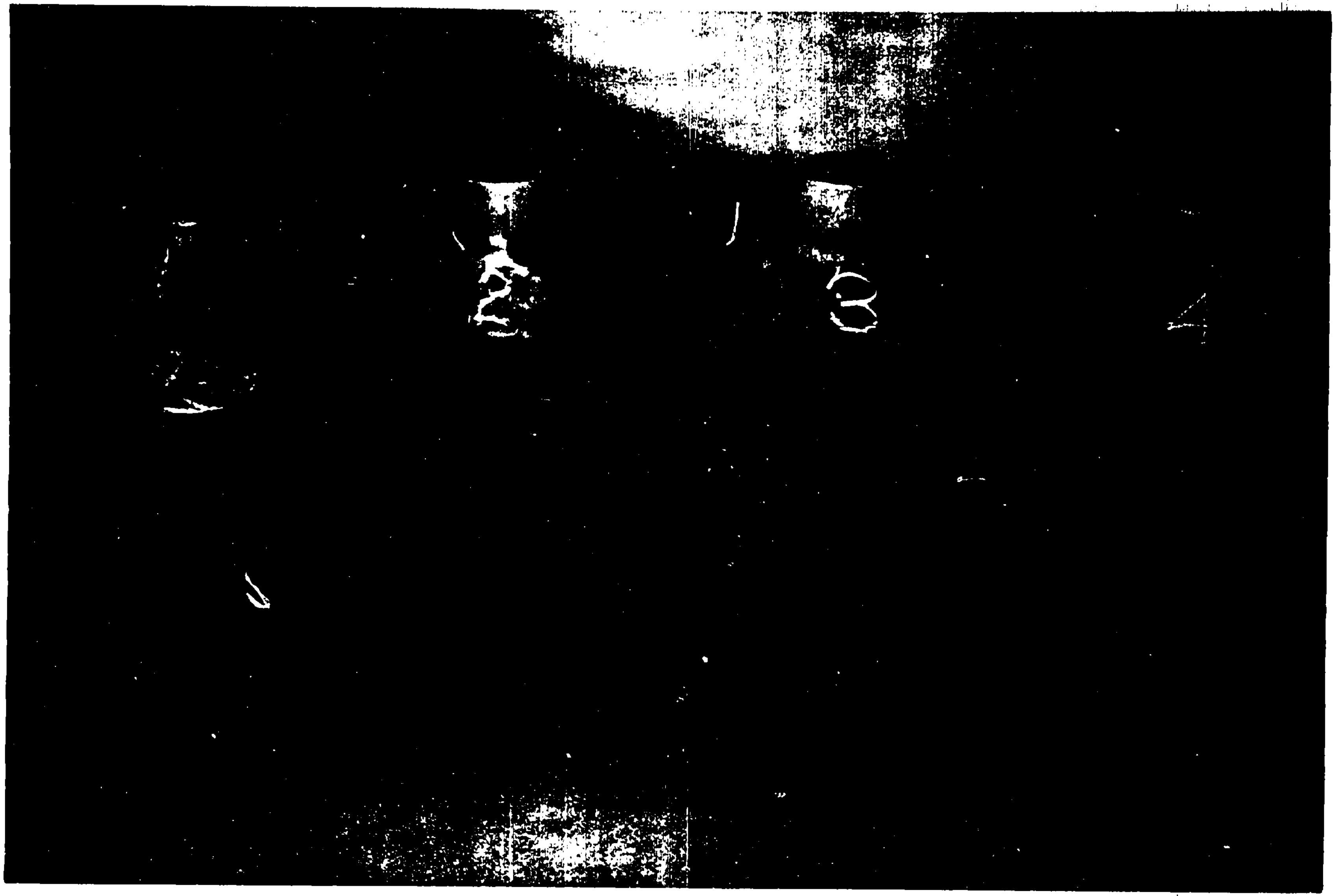


FIGURE 18 Potted Piece Method "D"

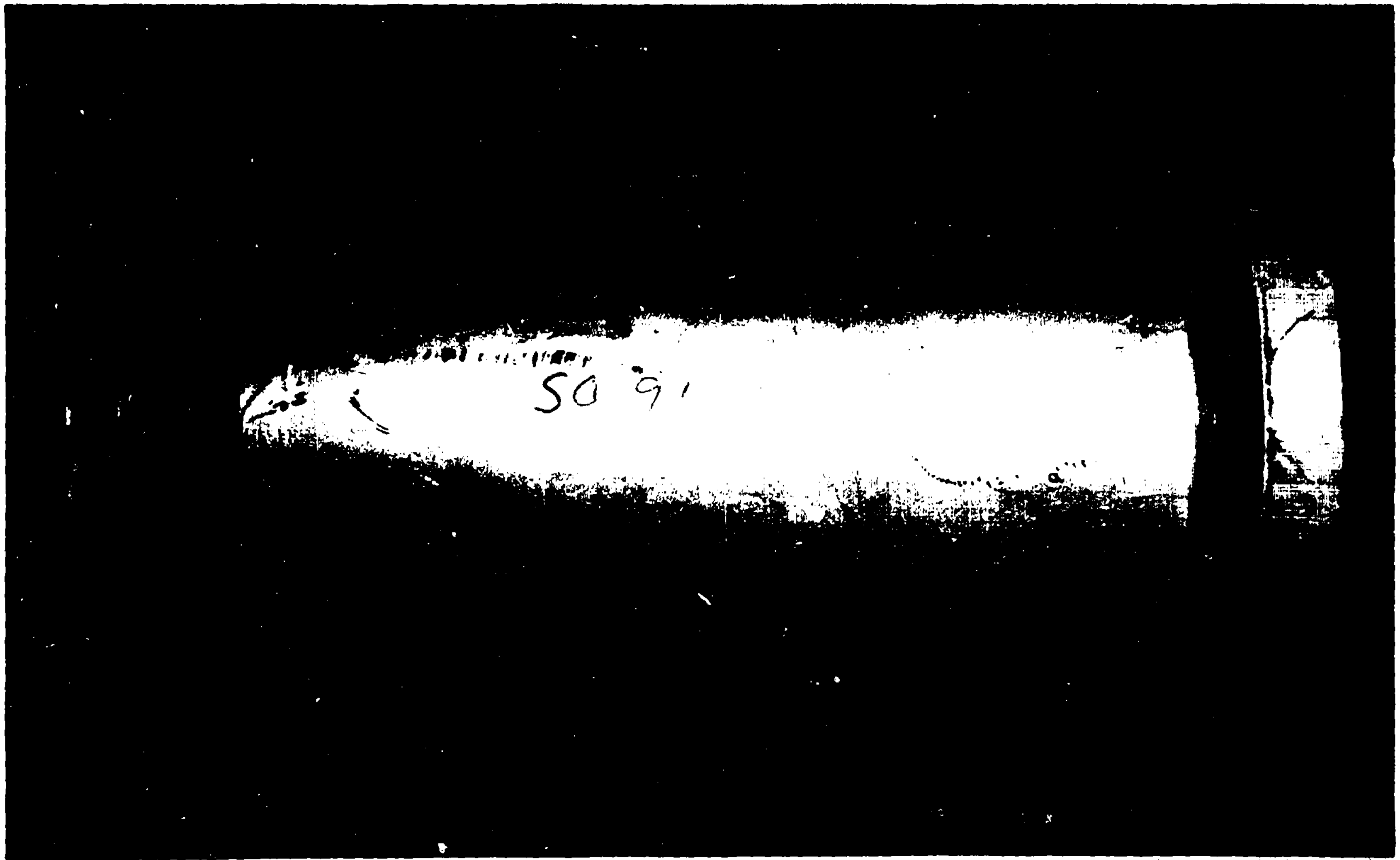


FIGURE 19 Method "D" Part After Forward Extrusion

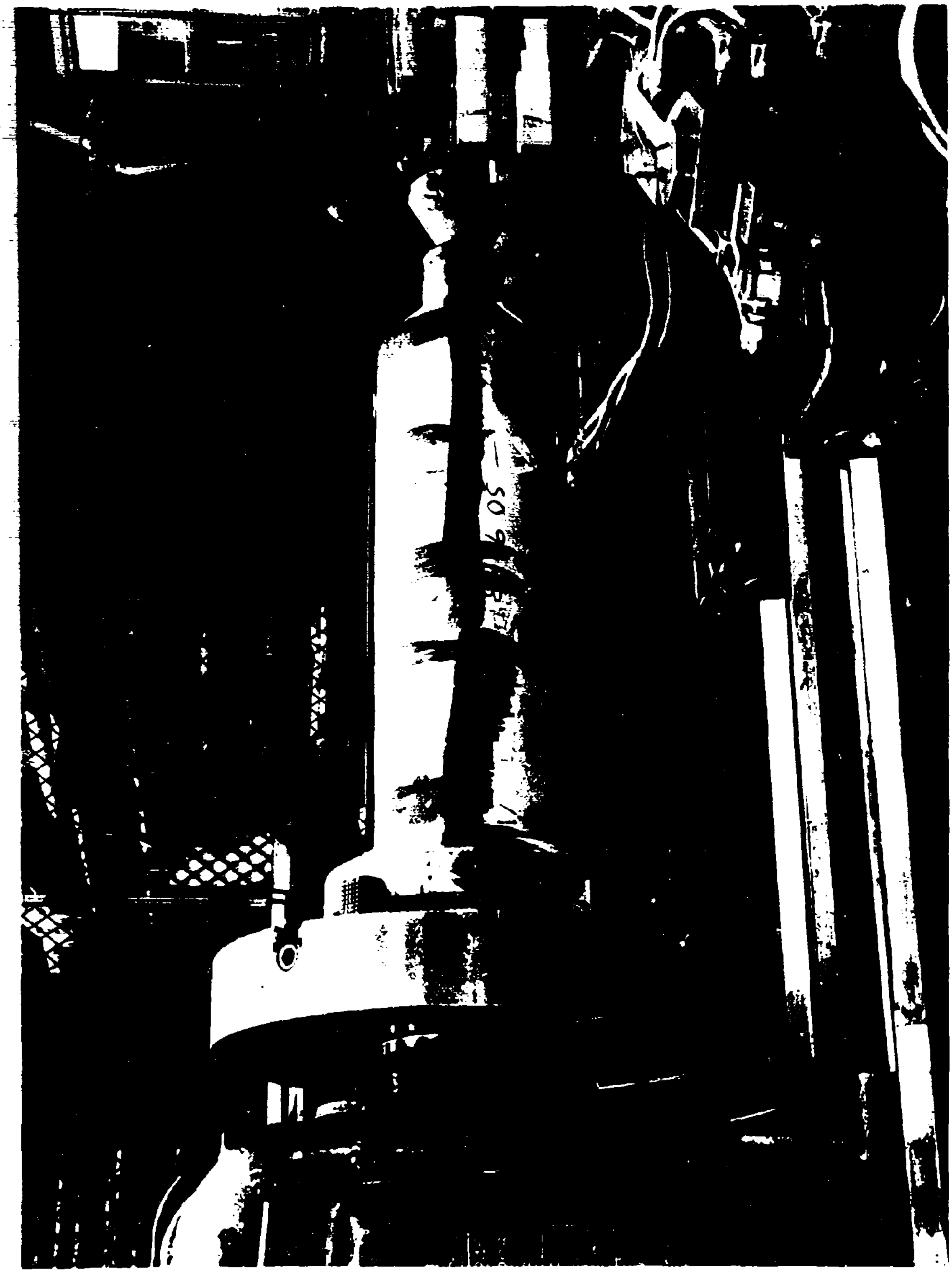


FIGURE 20 Extruded Piece on Tracer Lathe

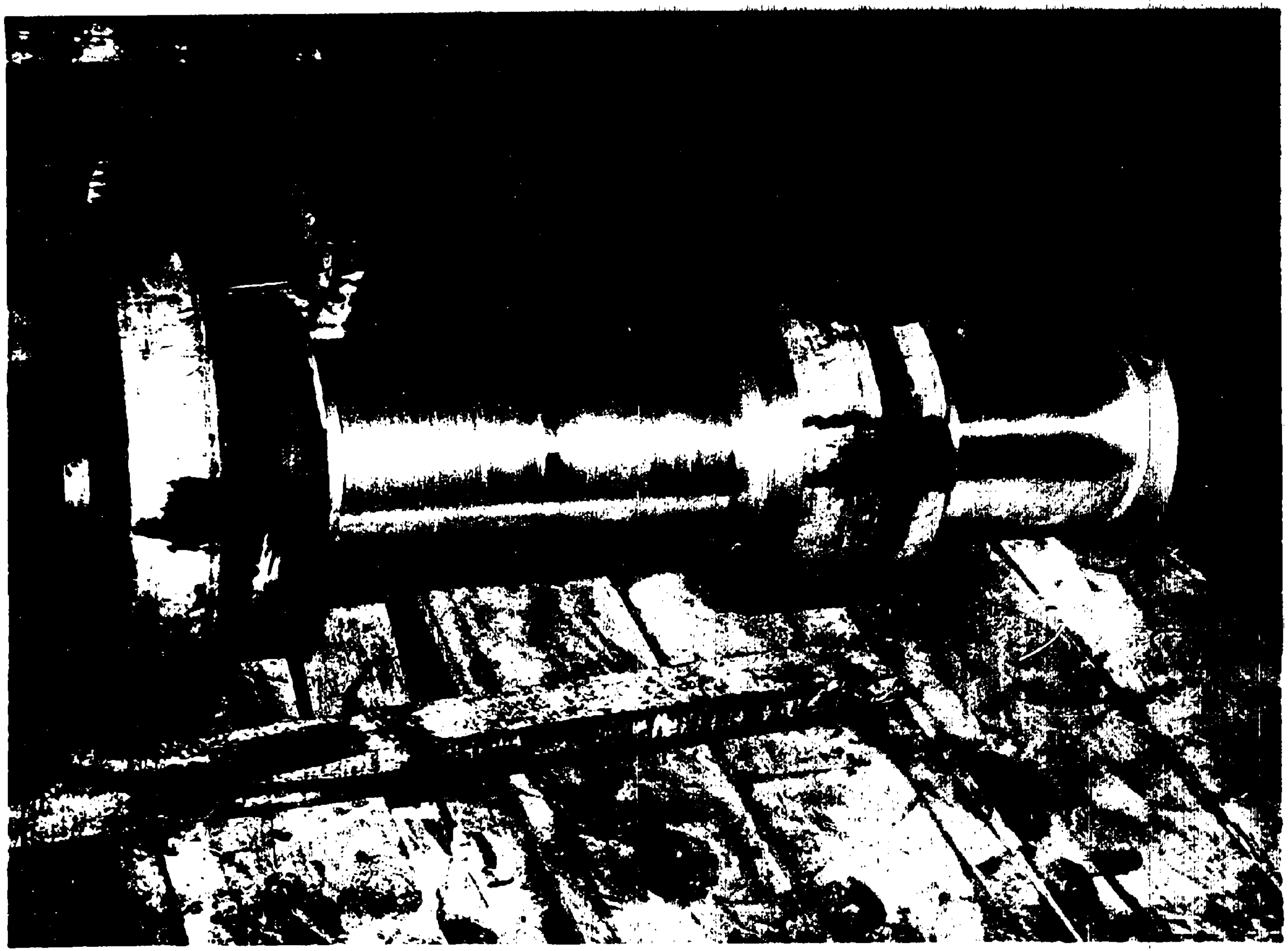


FIGURE 21 Extruded Piece After Turning Operation

Keller Set-up for Method "D" Machining

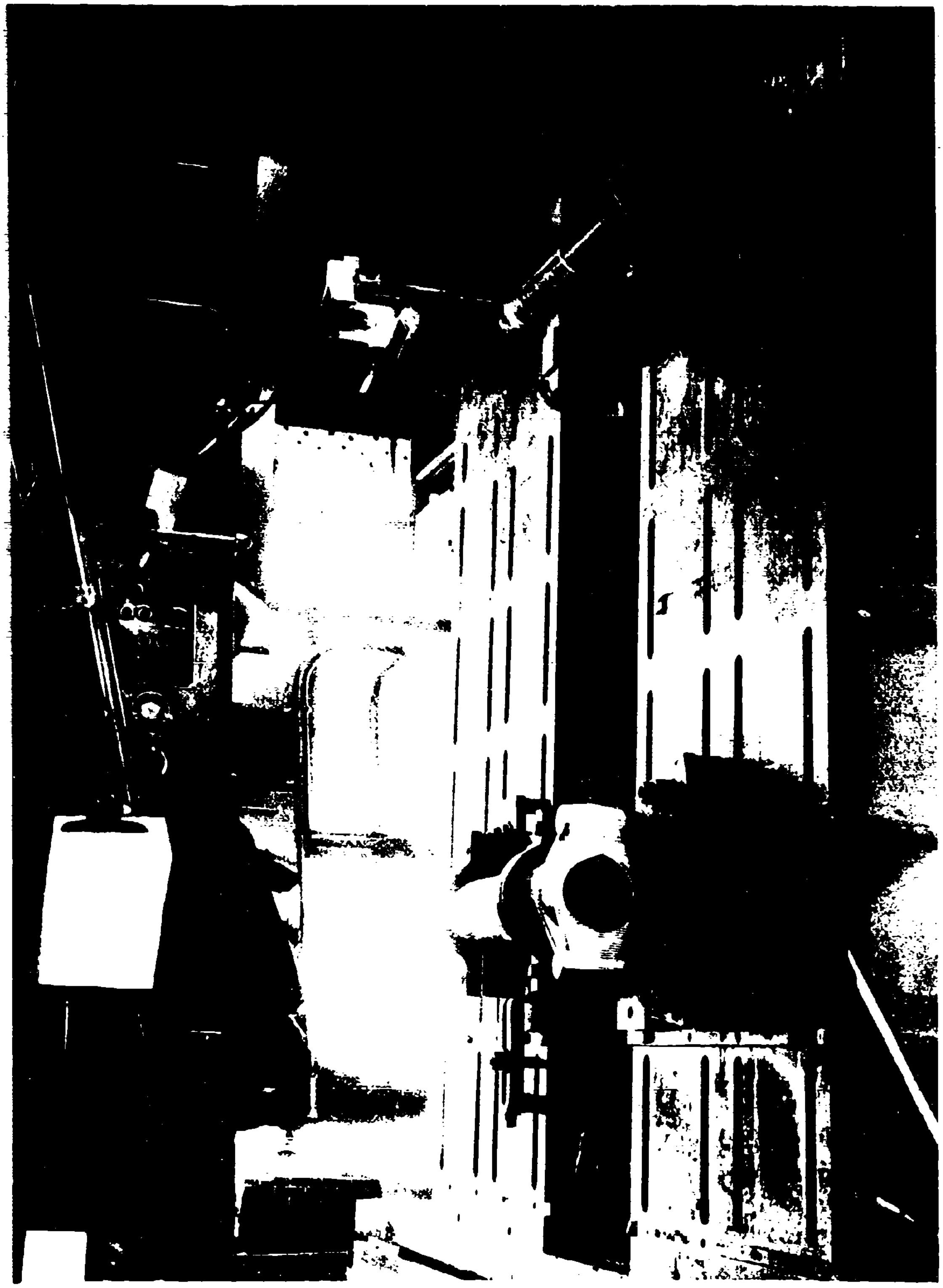


FIGURE 22

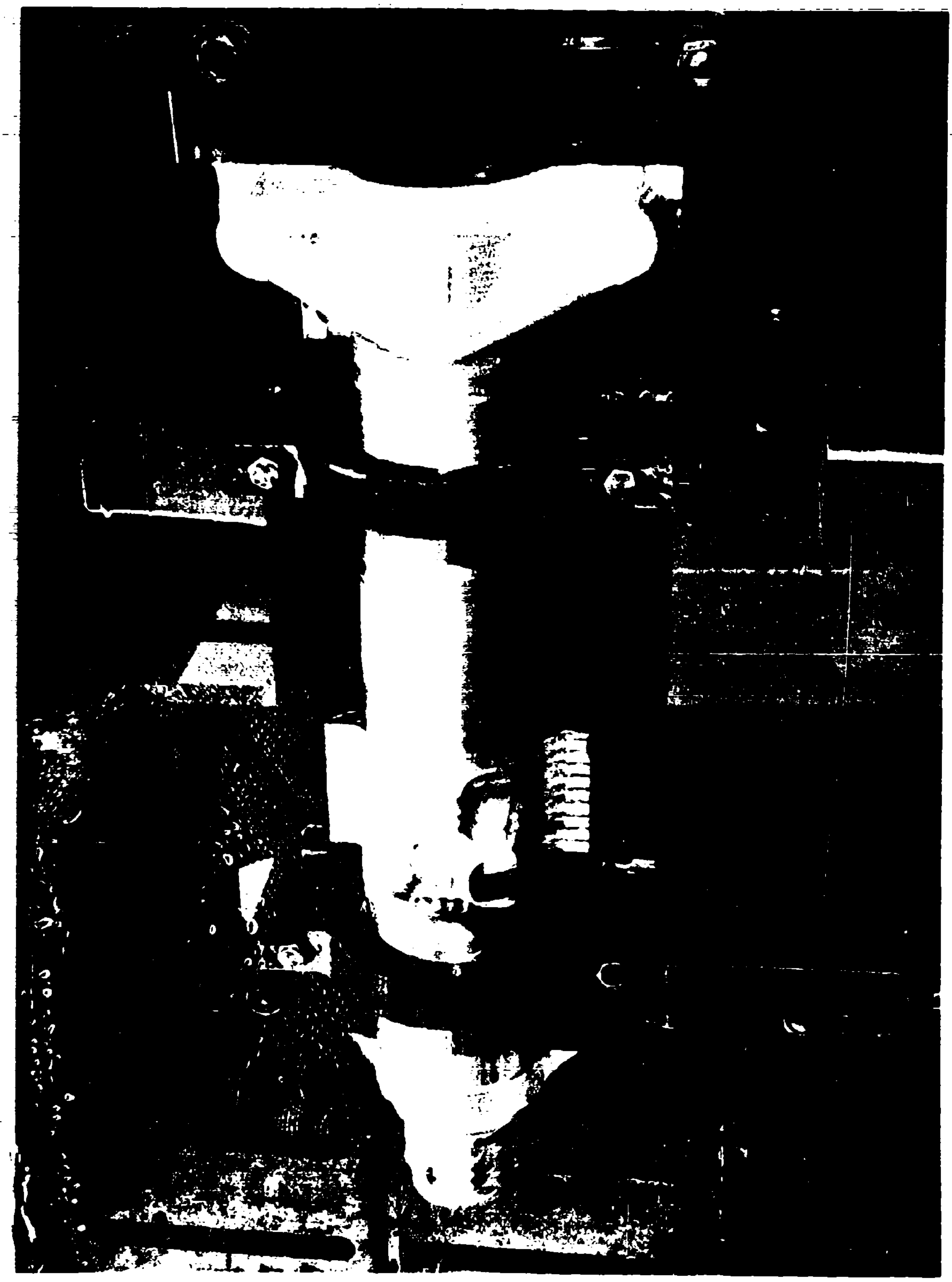


FIGURE 23 Side 1 During Kellering

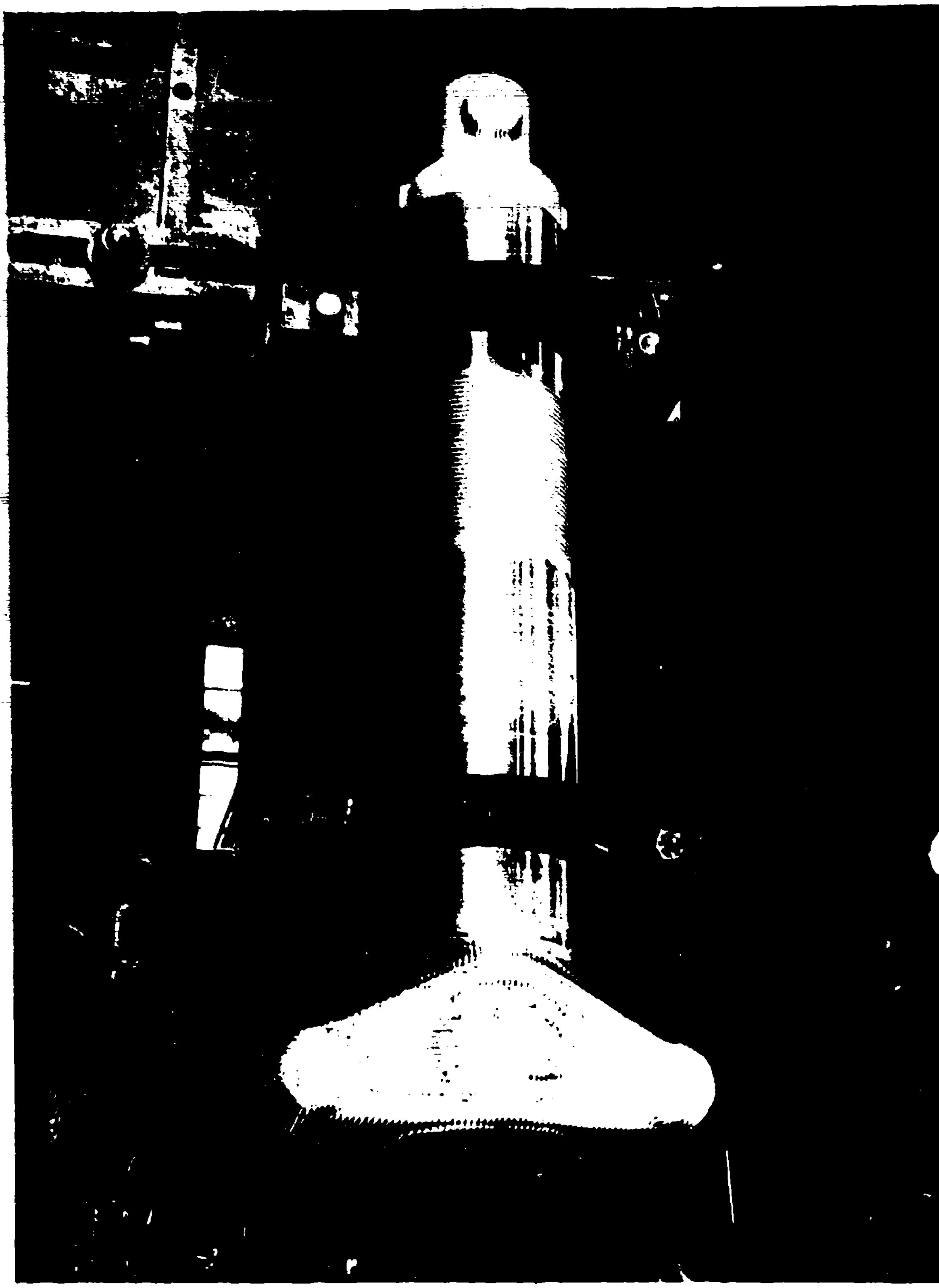


FIGURE 24 Side 2 During Kellering

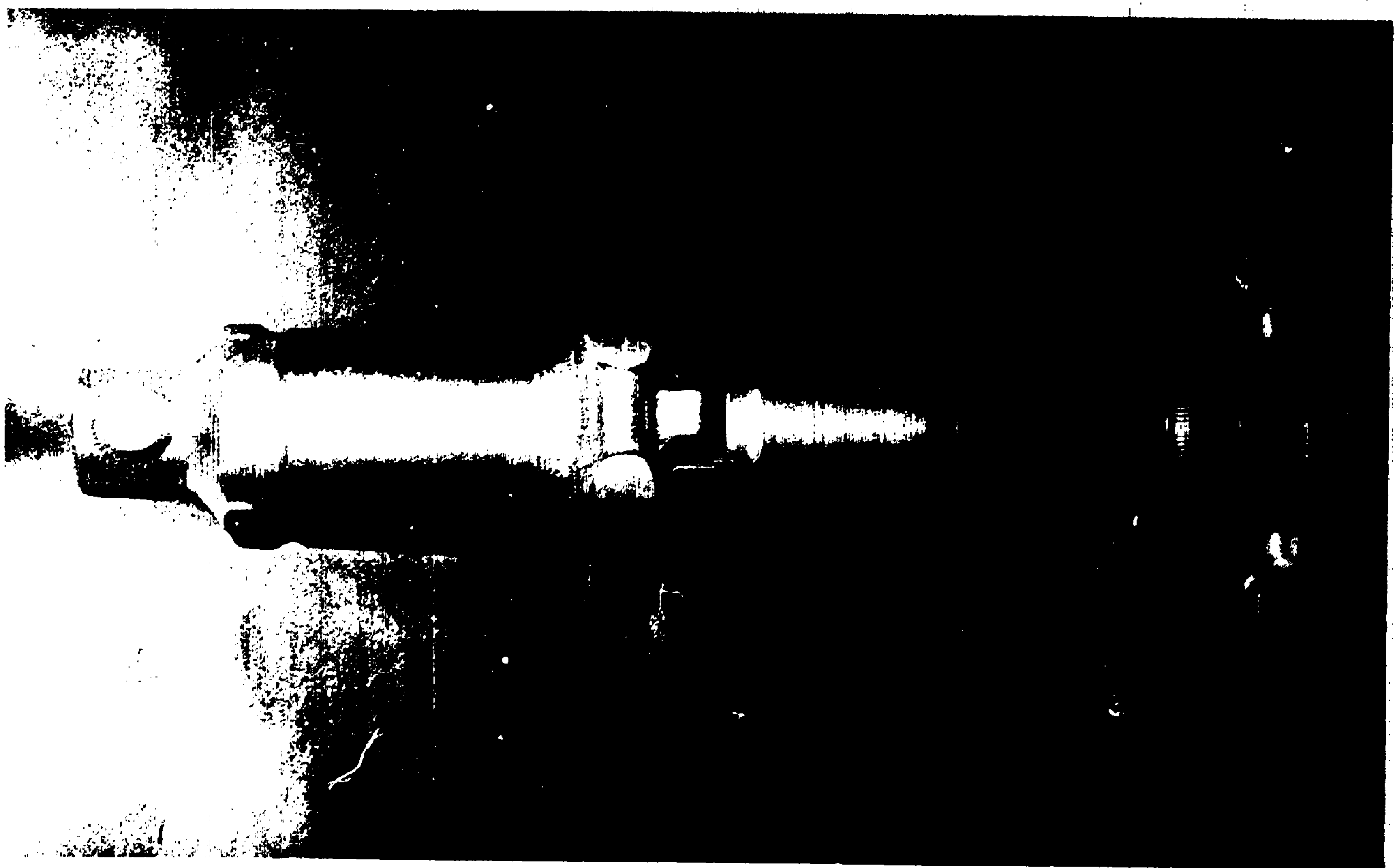


FIGURE 25 Finished Machine Pieces - Side No. 1

FIGURE 26 Finished Machined Piece - Side No. 2

FIGURE 27 Aluminum Heat Treating Furnace - Discharge End. The quench tank is just outside the door.

FIGURE 28 Forging Loaded ready for solution treatment at discharge end of furnace.

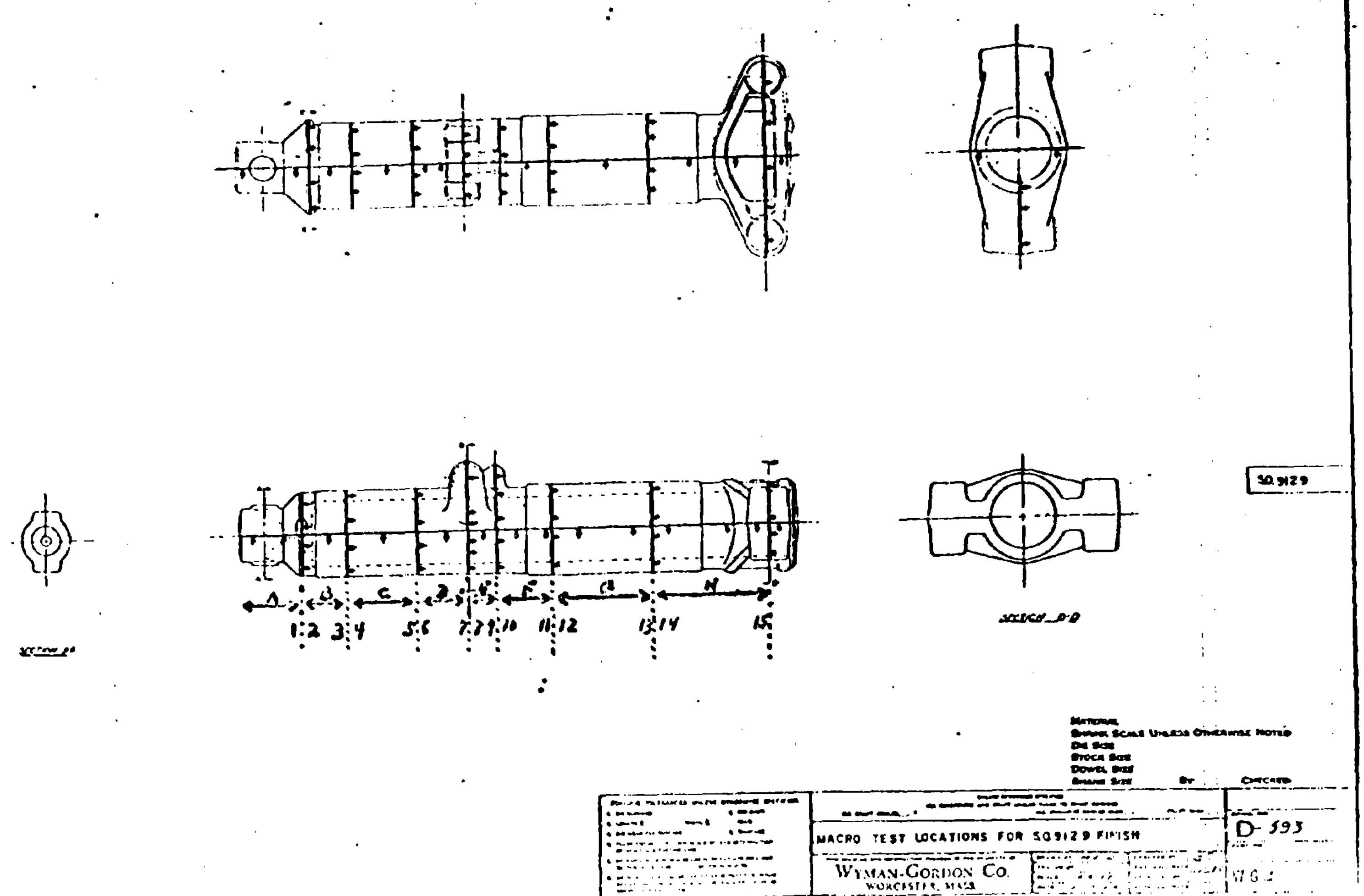


FIGURE 29 Macro Test Locations

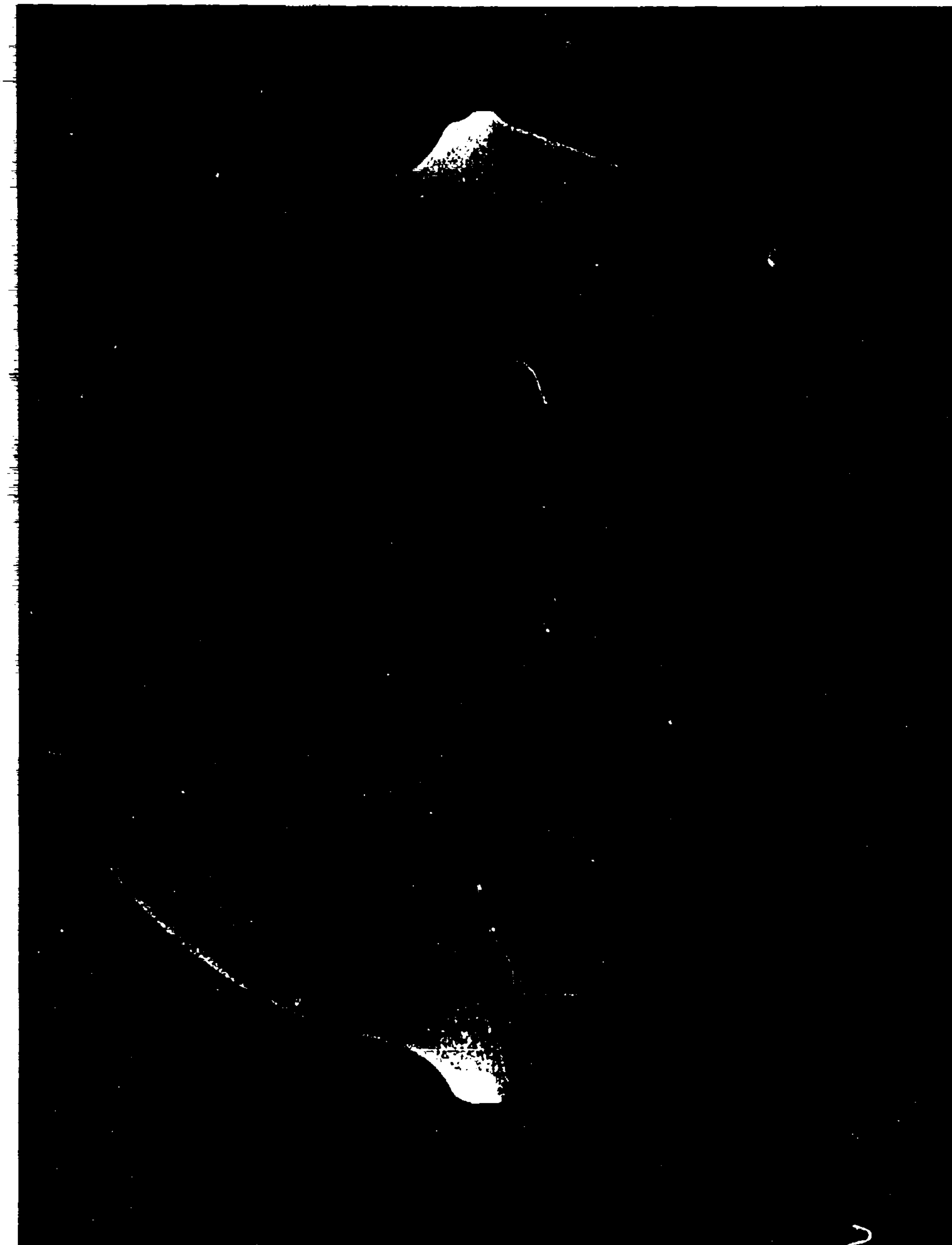


FIGURE 30 Section B2 of Forging No. 5, Method "A"
Etchant 10% NaOH

FIGURE 31 Section B2 of Forging No. 8, Method "B" - Etchant 10% NaOH

FIGURE 32 Section B2 of Forging No. 12, Method "C" - Etchant 10% NaOH

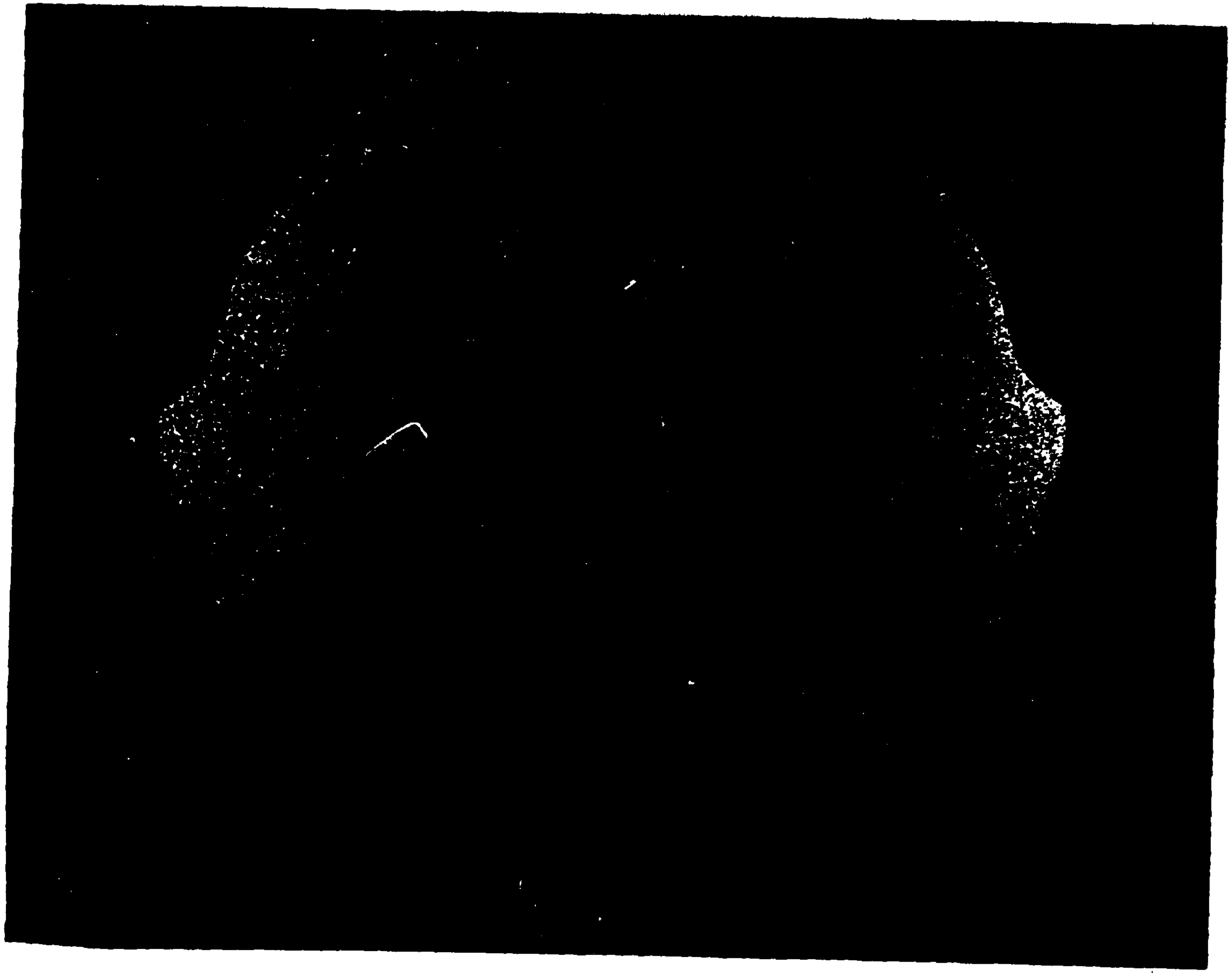


FIGURE 33 Section B2 of Forging No. 16, Method "D" - Etchant 10% NaOH

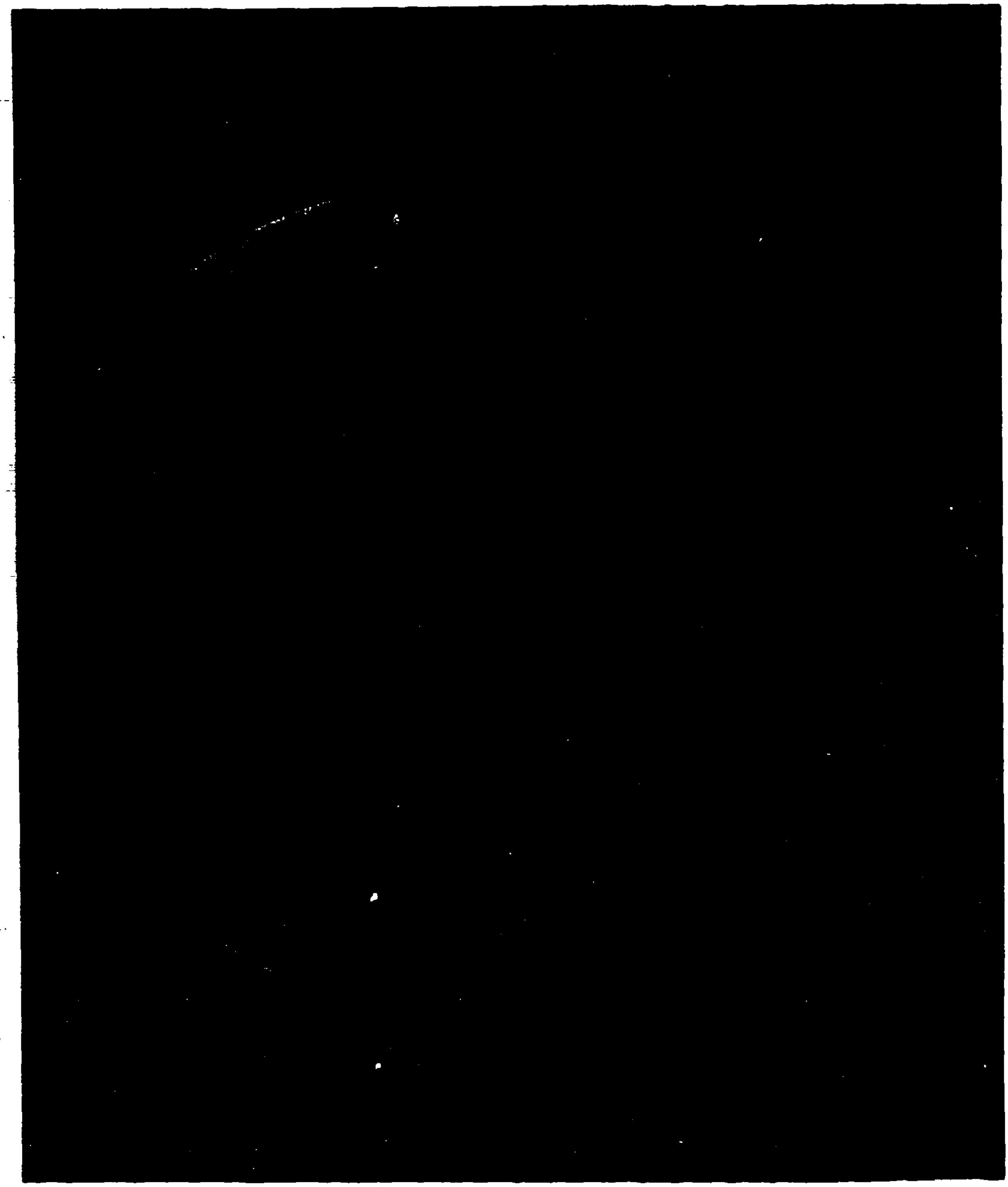


FIGURE 34 Section C4 of Method "A" - Etchant 10% NaOH

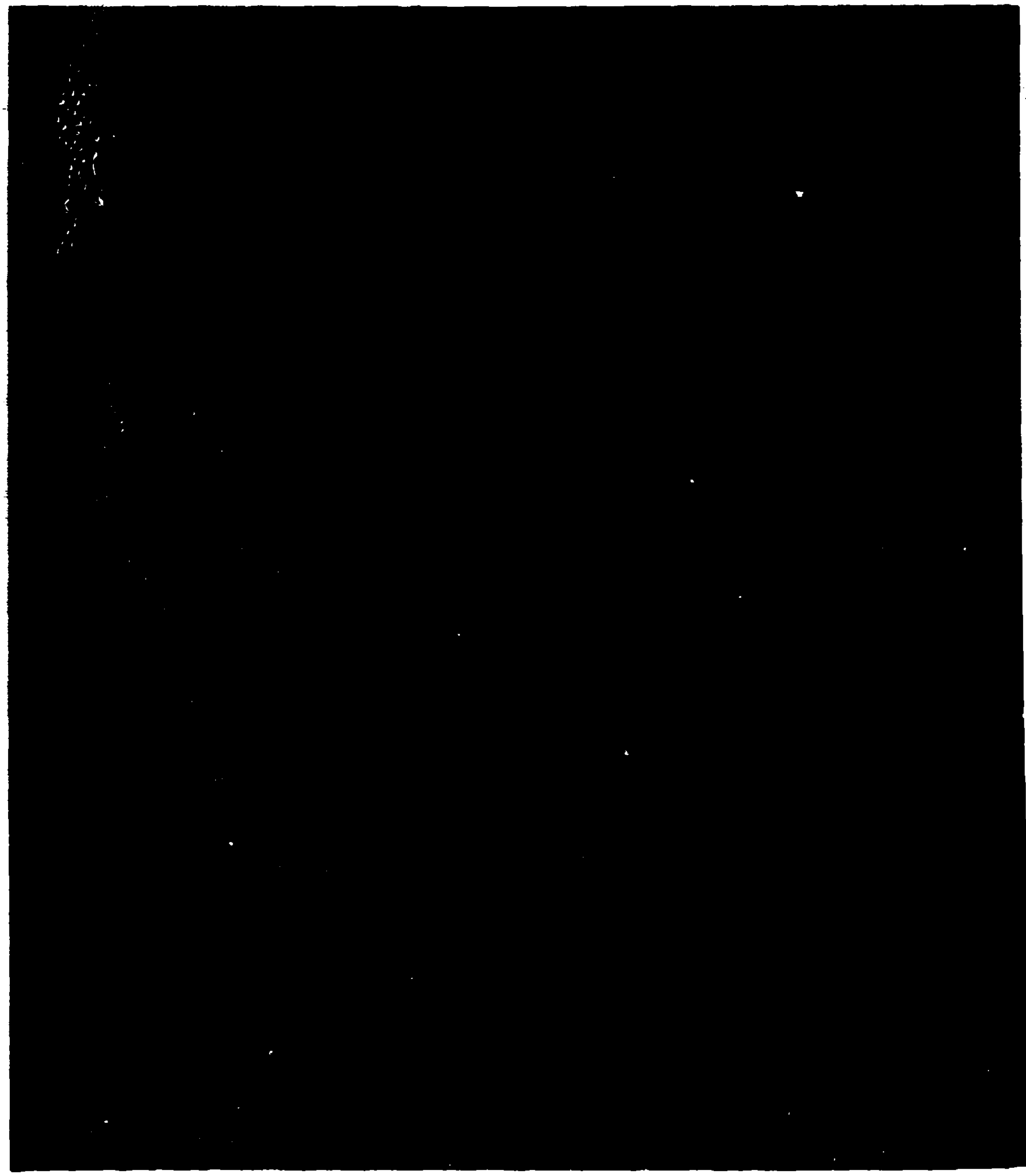


FIGURE 35 Section C4 of Method "2" - Etchant 10% NaOH

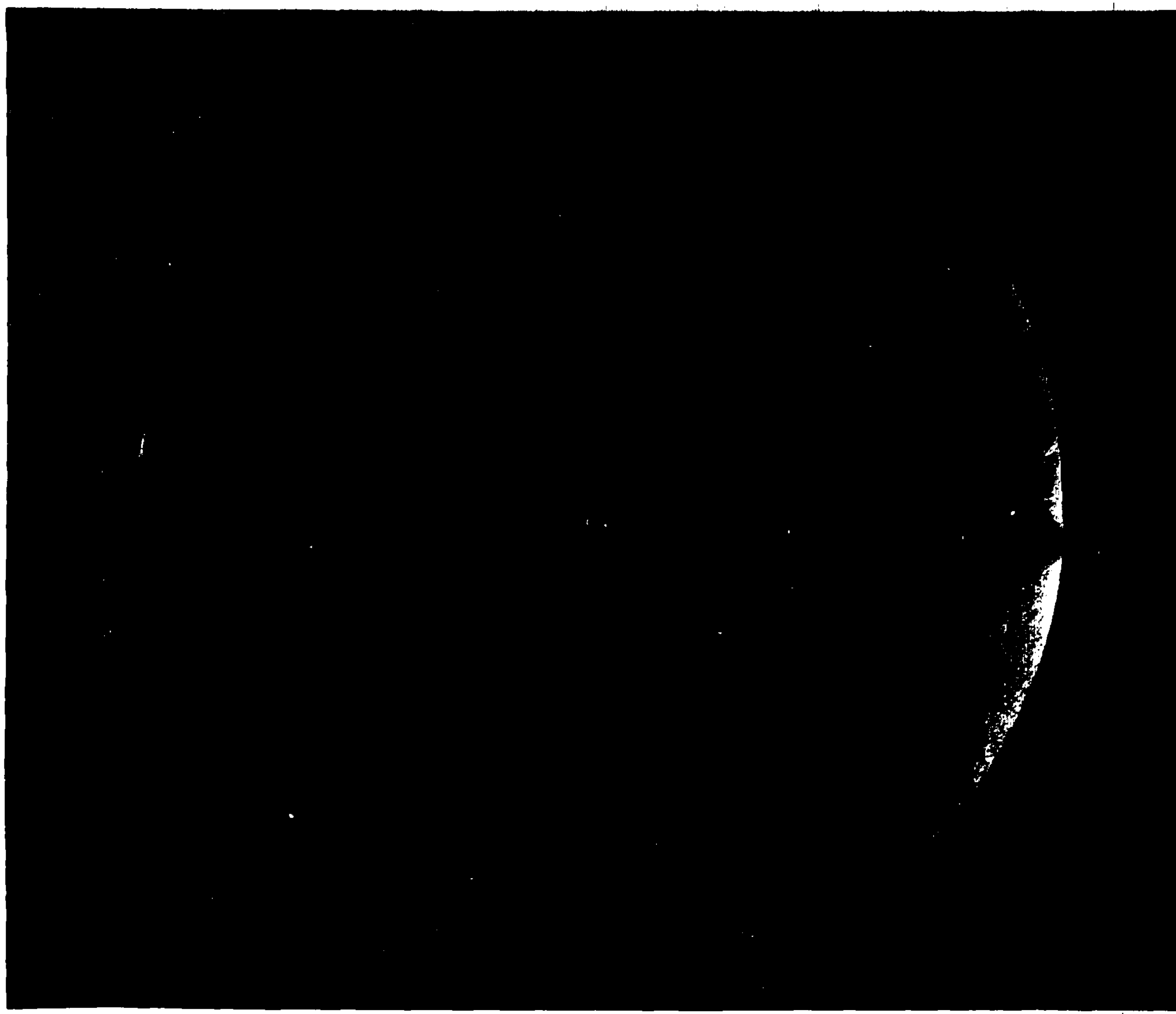


FIGURE 36 Section C4, Method "C" - Etchant 10% NaOH

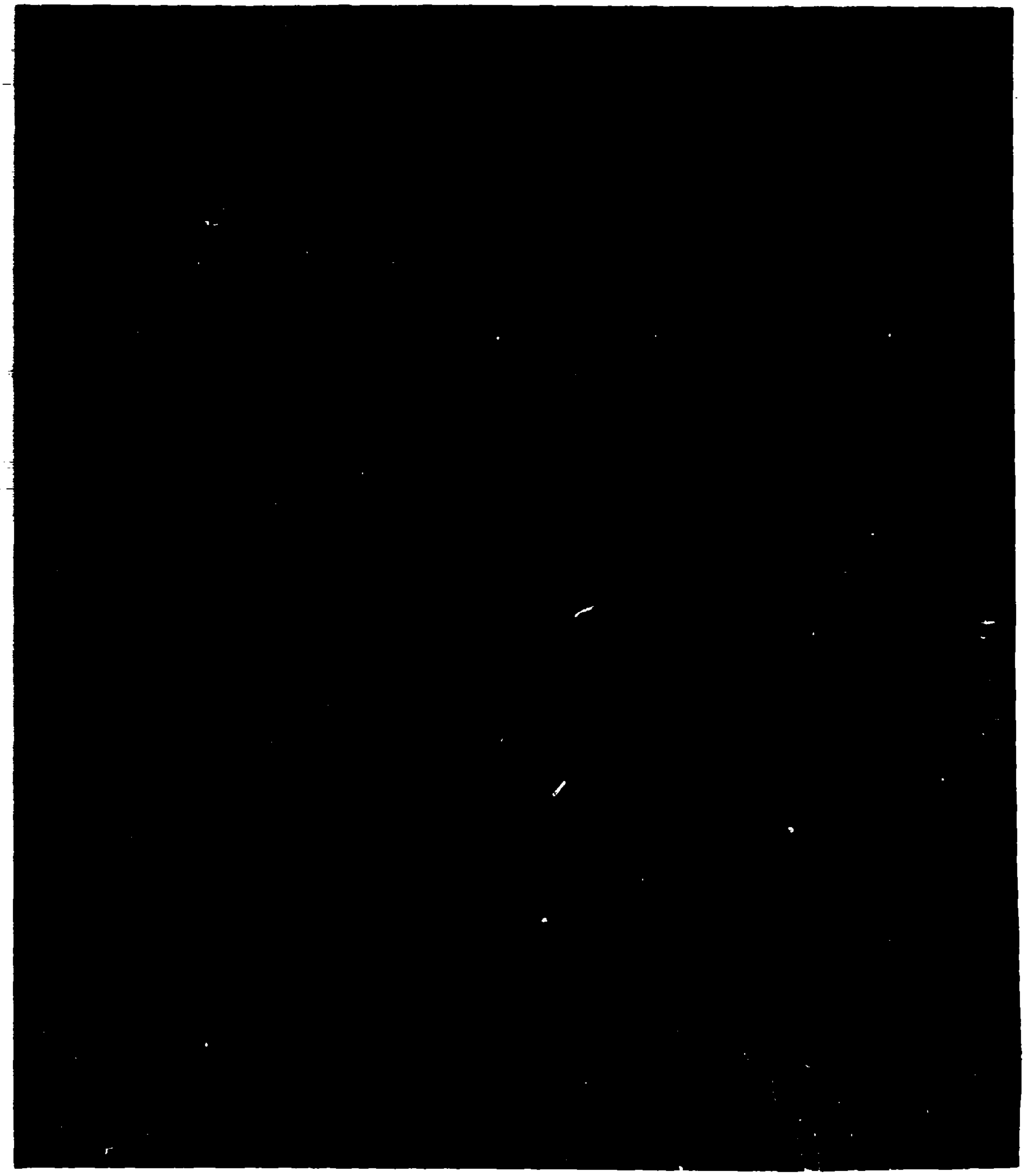


FIGURE 37 Section C4, Method "D" - Etchant 10% NaOH

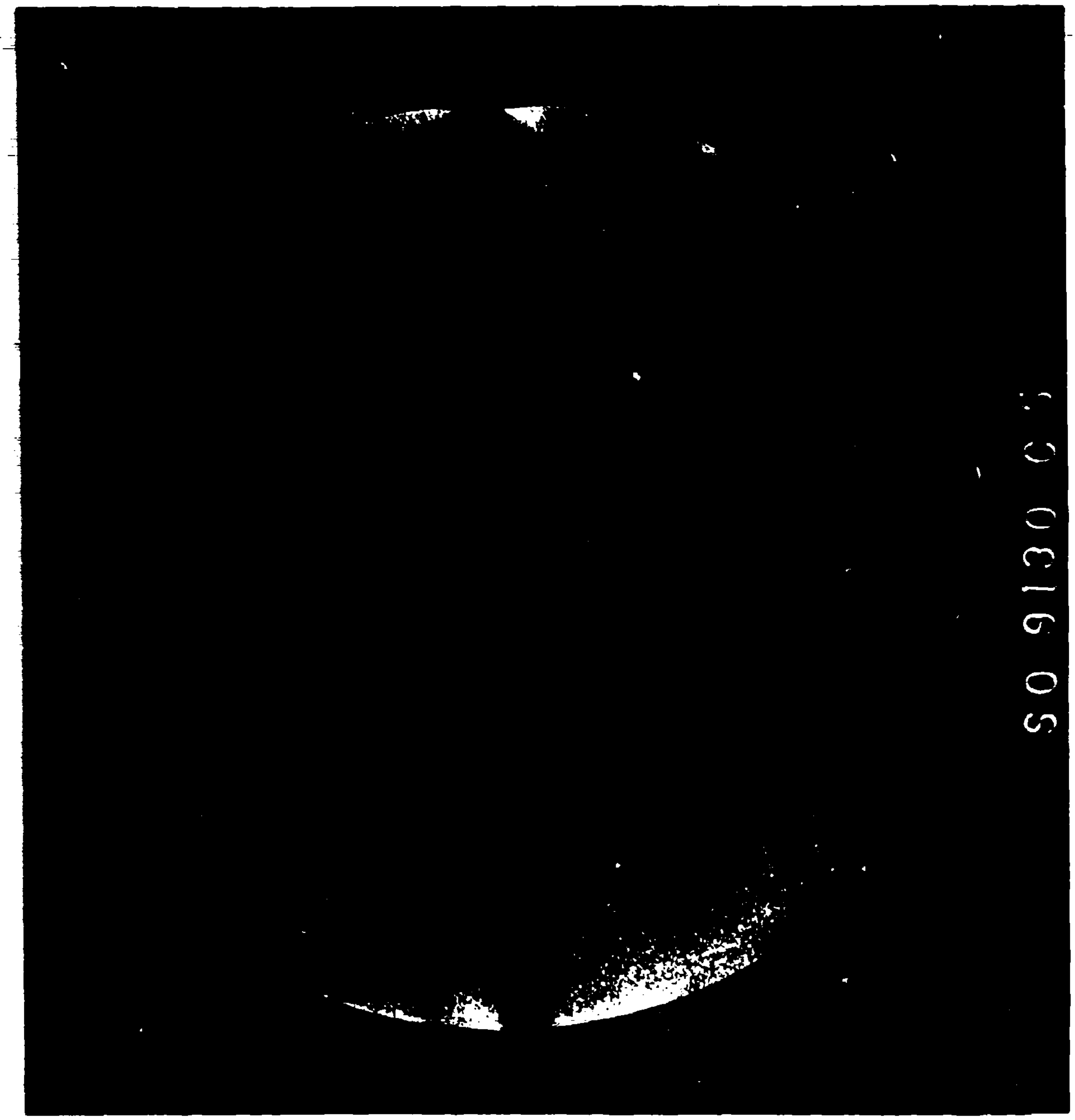


FIGURE 38 Section C5, Method "A" - Etchant 10% NaOH

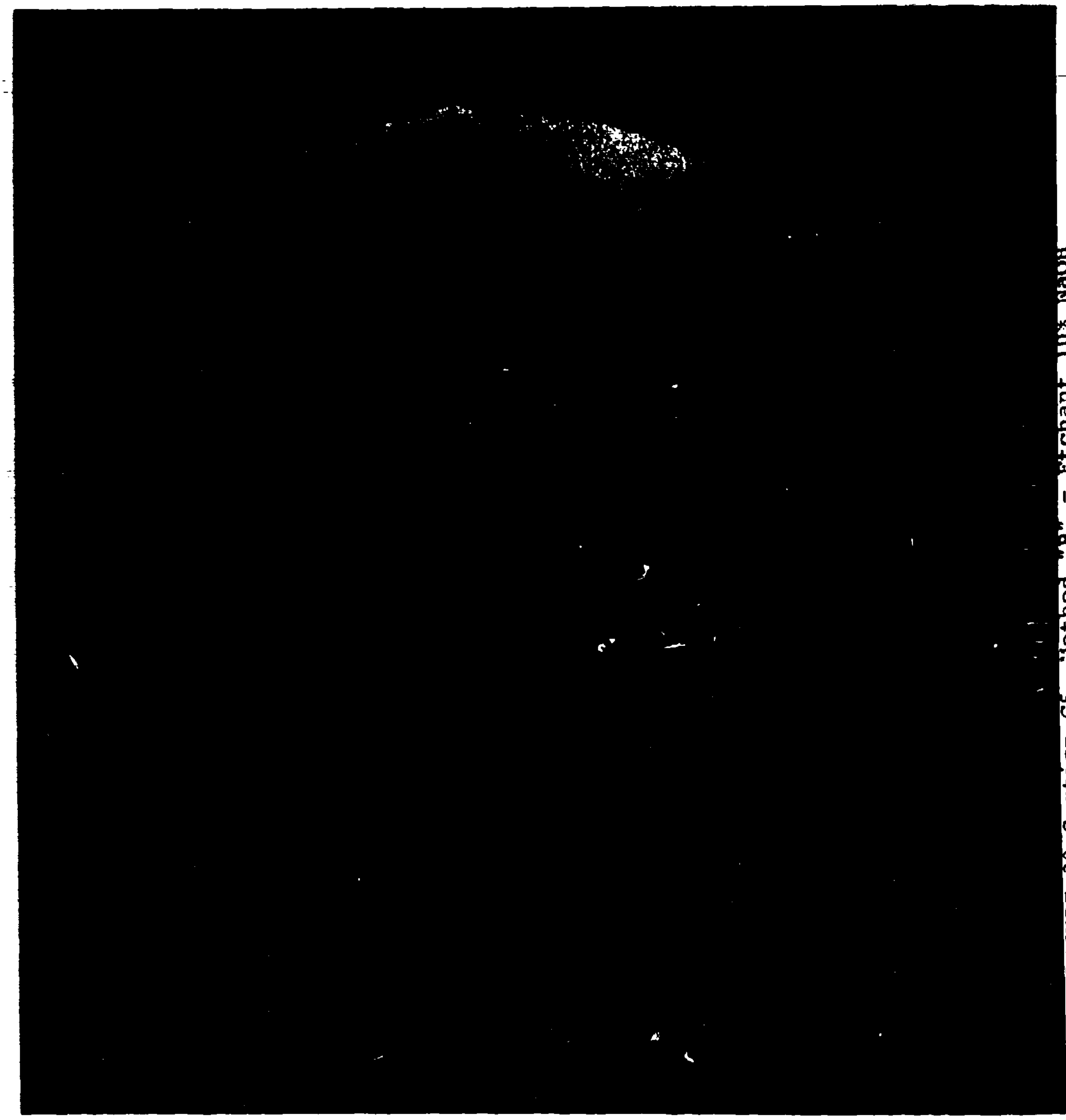


FIGURE 33, Section C5, Method "B" - Etchant 10% NaOH

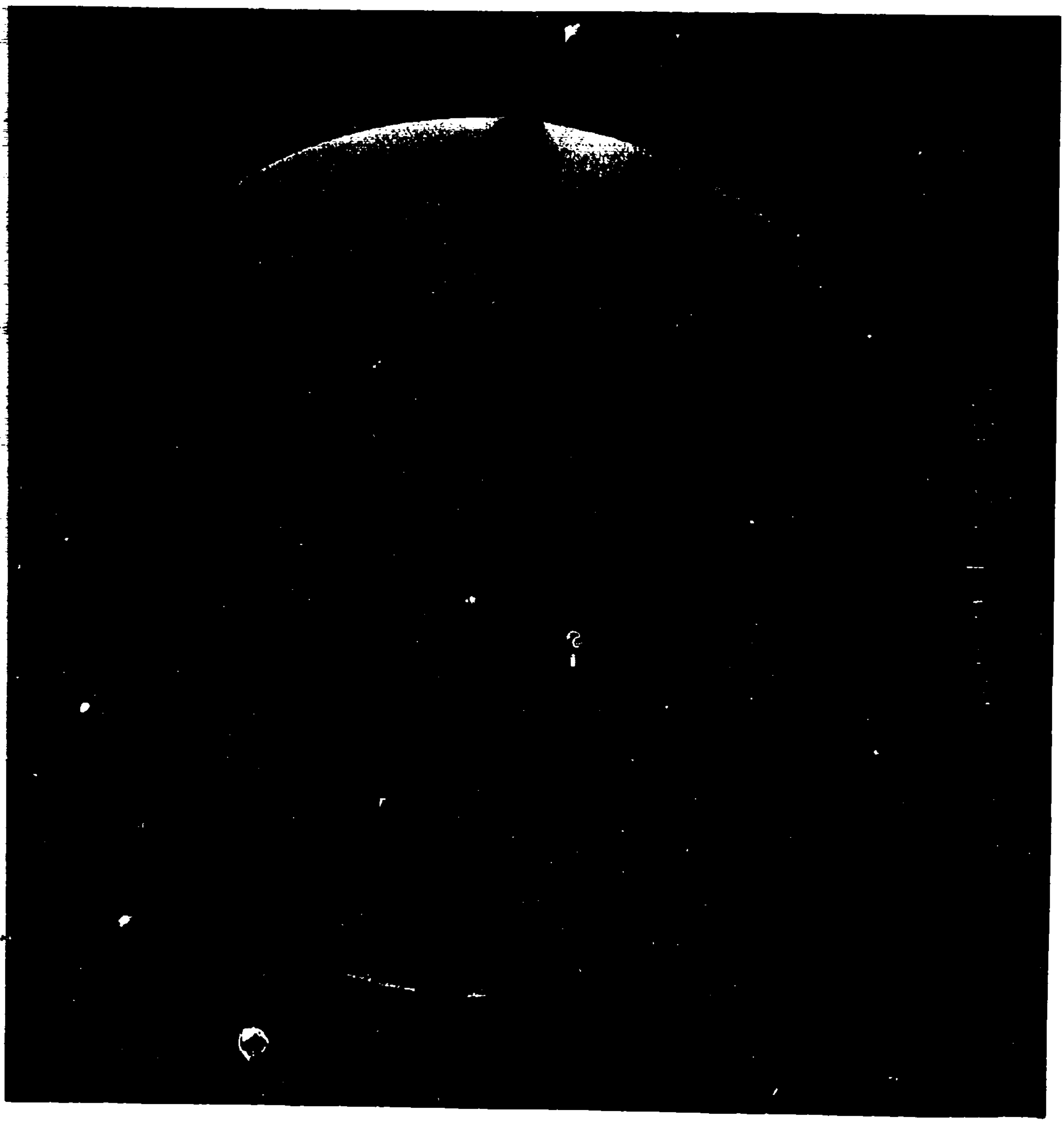


FIGURE 40 Section C5, Method "C" - Etchant 10% NaOH

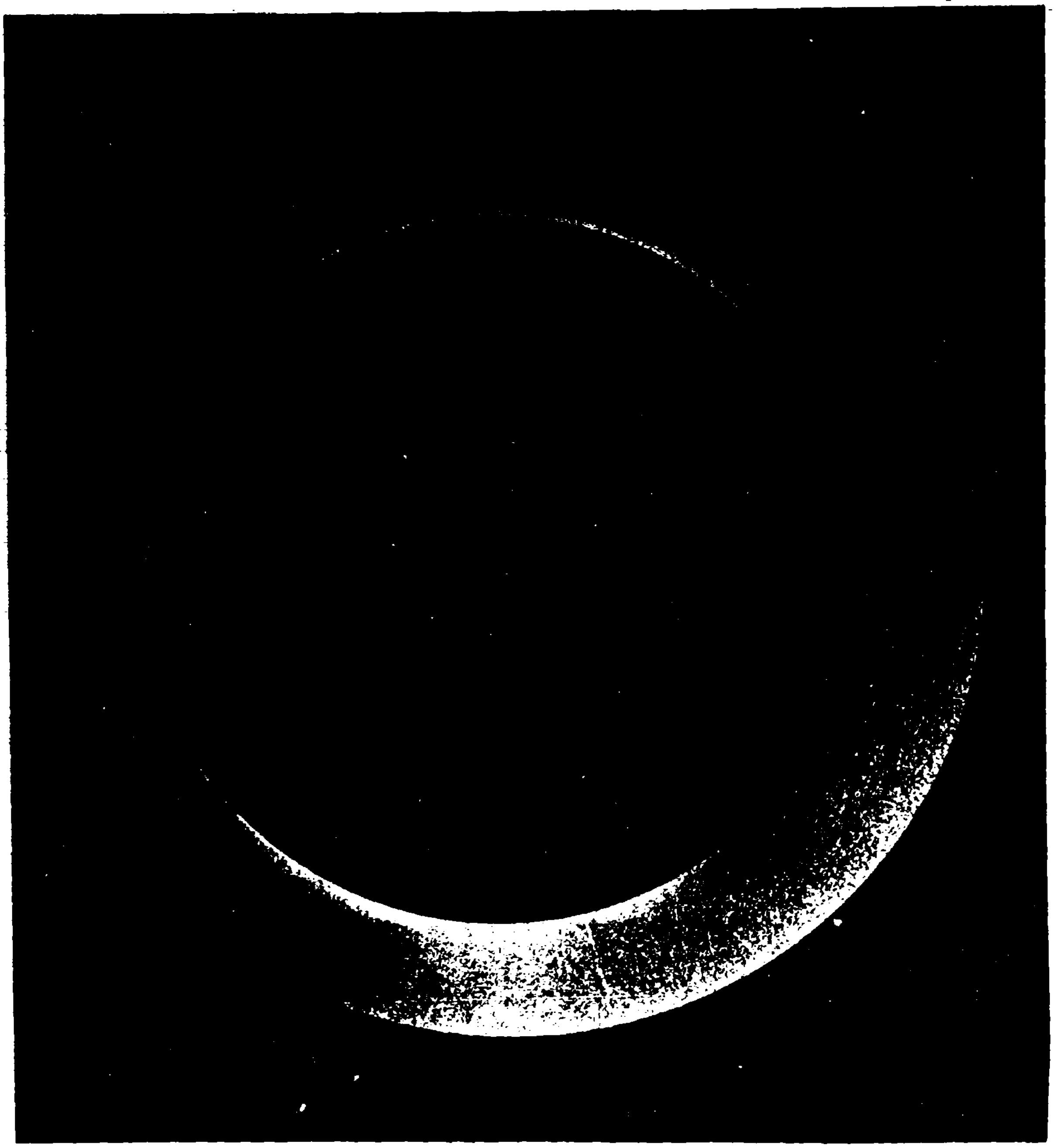


FIGURE 41 Section C5, Method "D" - Etchant 10% NaOH

FIGURE 42 Section D7, Method "A" - Etchant 10% NaOH

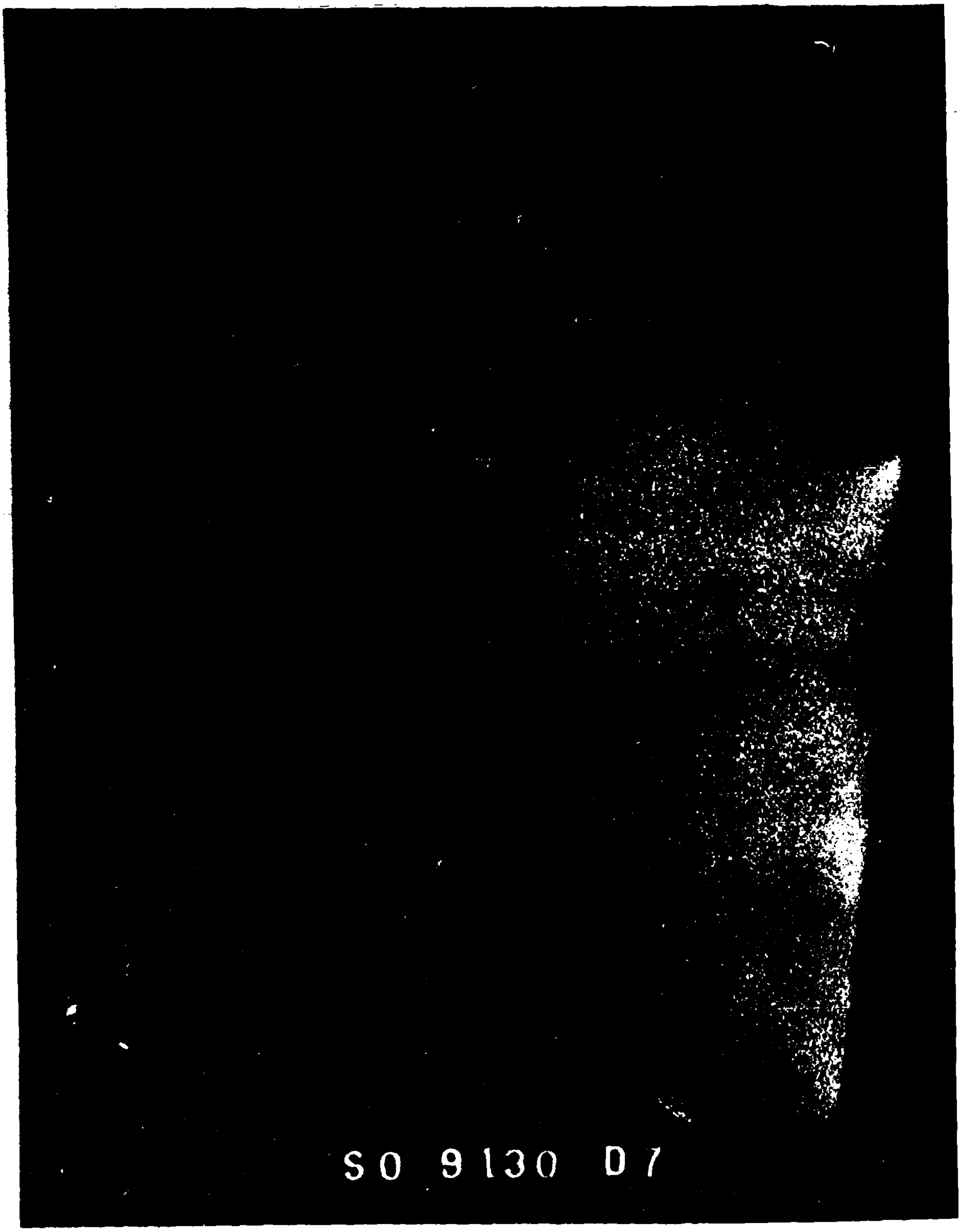


FIGURE 43 Section D7, Method "B" - Etchant 10% NaOH

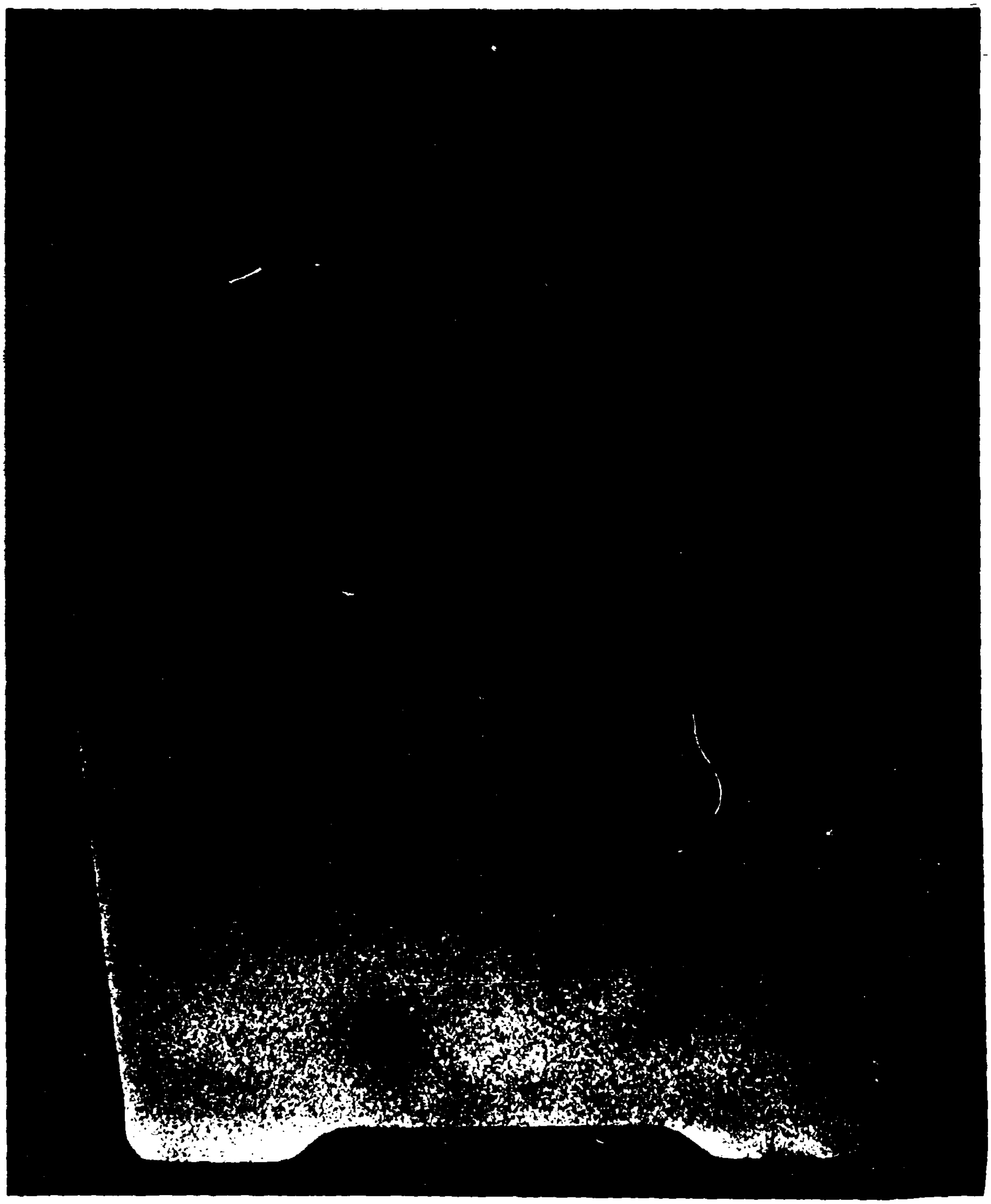


FIGURE 44 Section D7, Method "C" - Etchant 10% NaOH

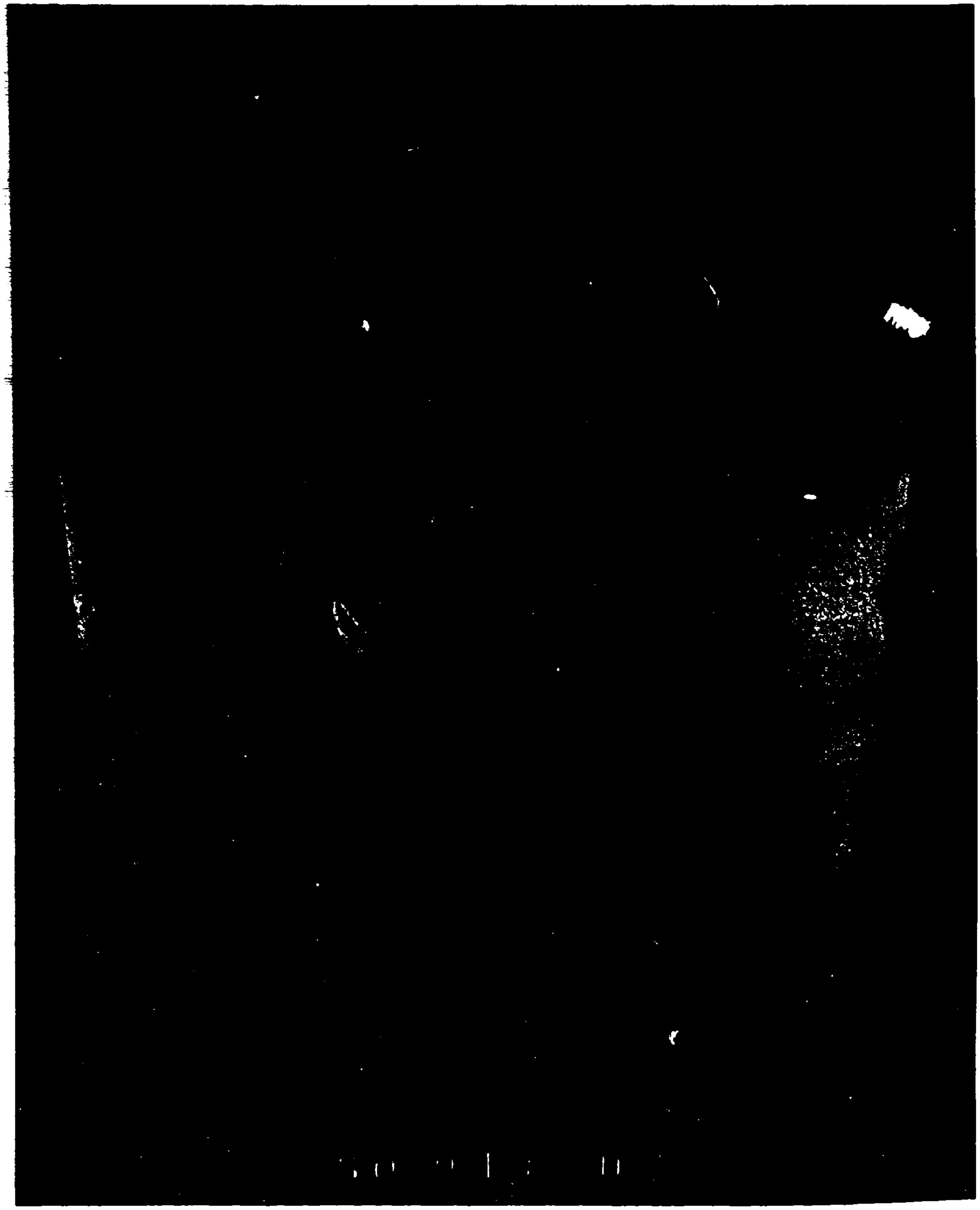


FIGURE 45 Section D7, Method "D" - Etchant 10% NaOH

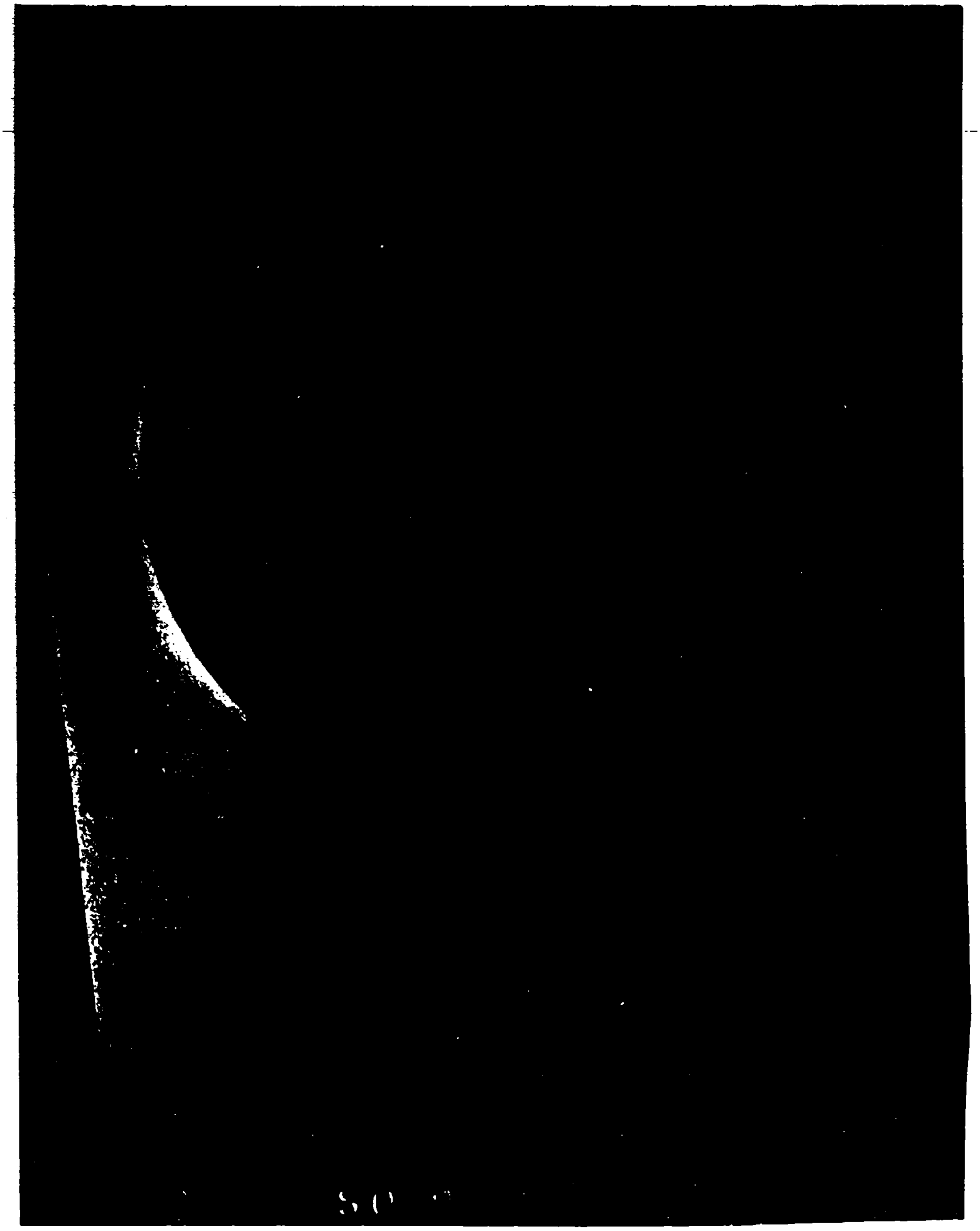


FIGURE [illegible] Section [illegible]10, Method 'A' - Etchant 10% NaOH

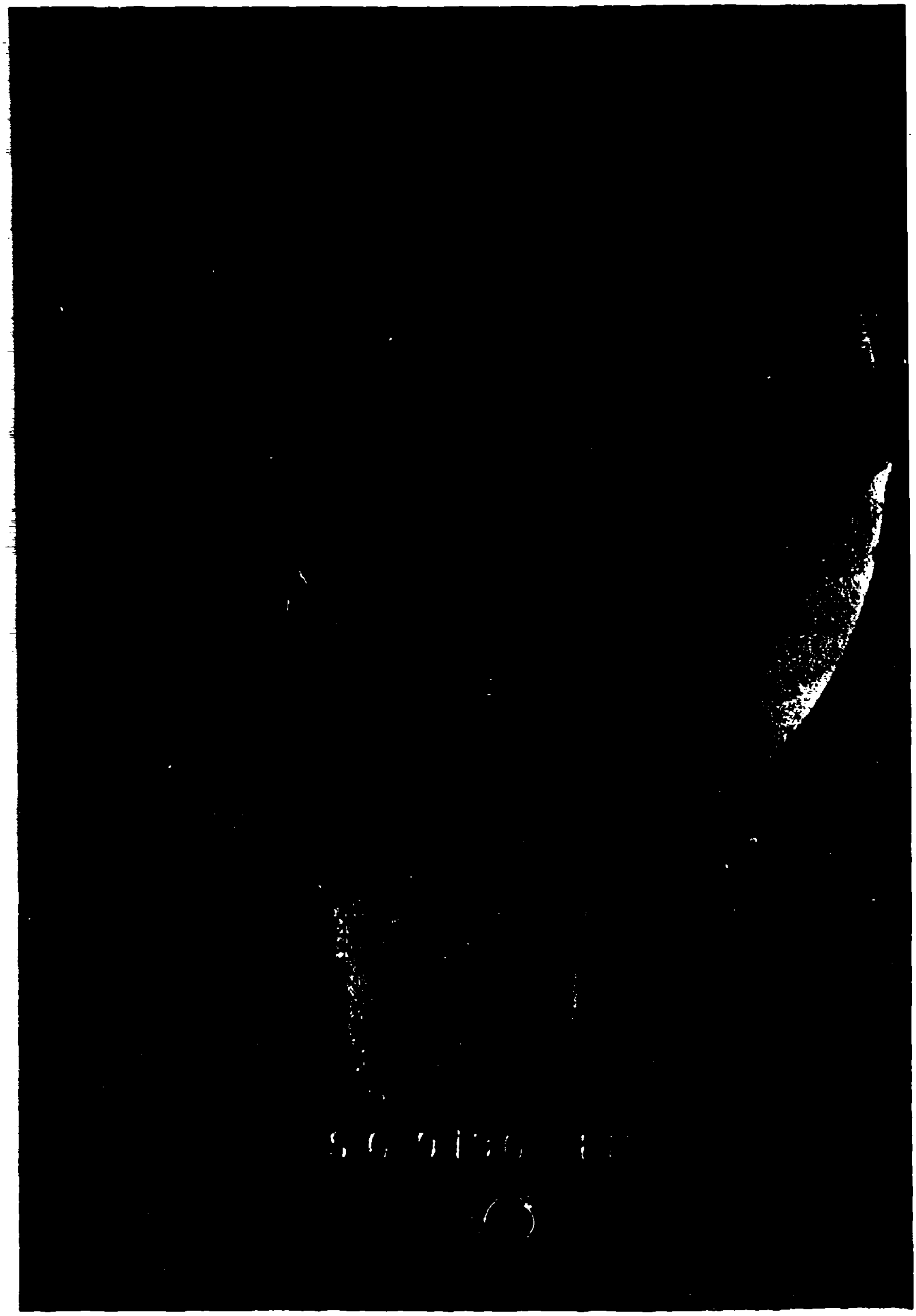


FIGURE 47 Section F10, Method "B" - Etchant 10% NaOH

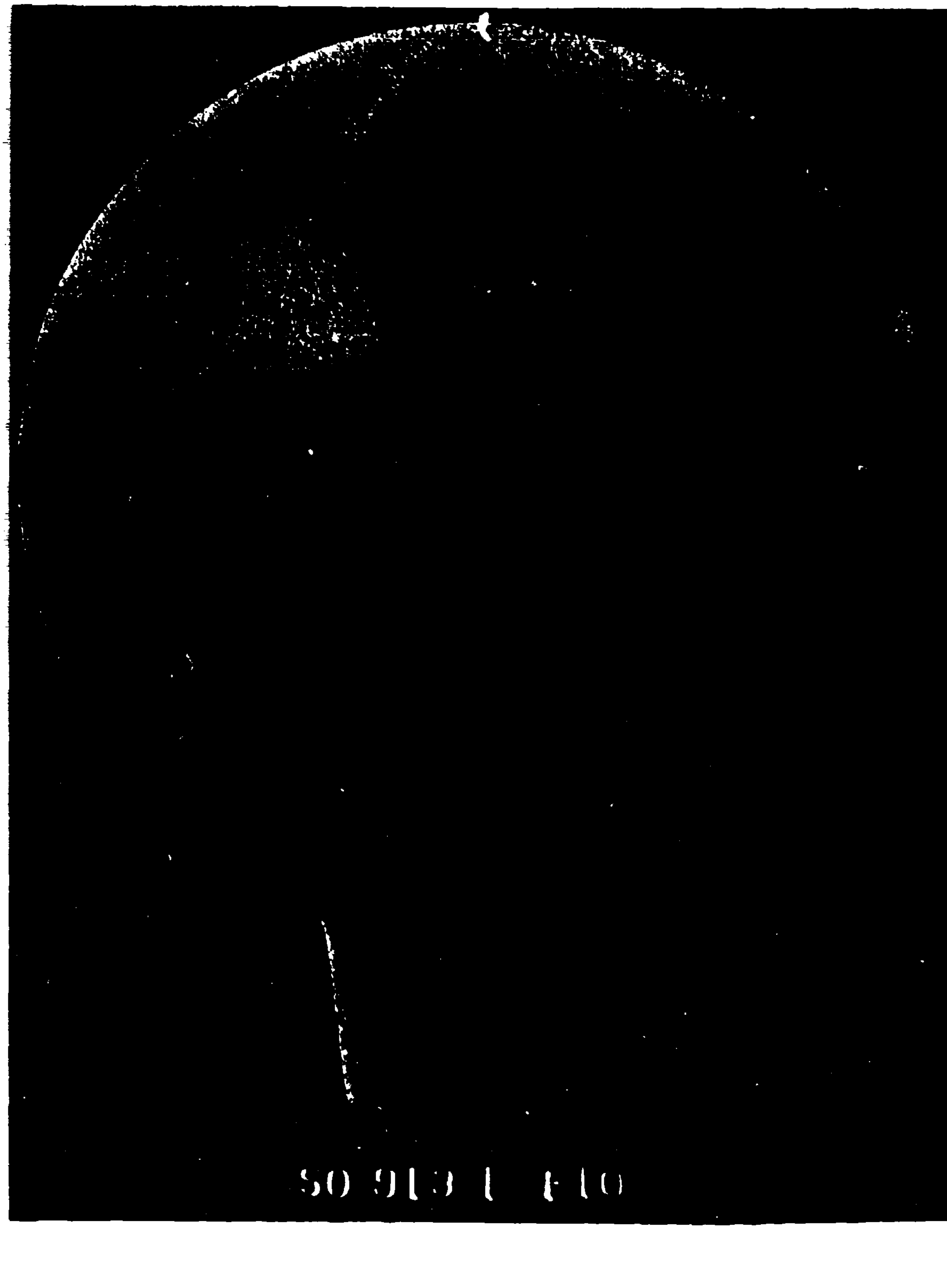


FIGURE 48 Section F10, Method "C" - Etchant 10% NaOH

FIGURE 43 Section F10, Method 'D' - Etchant 10% NaOH

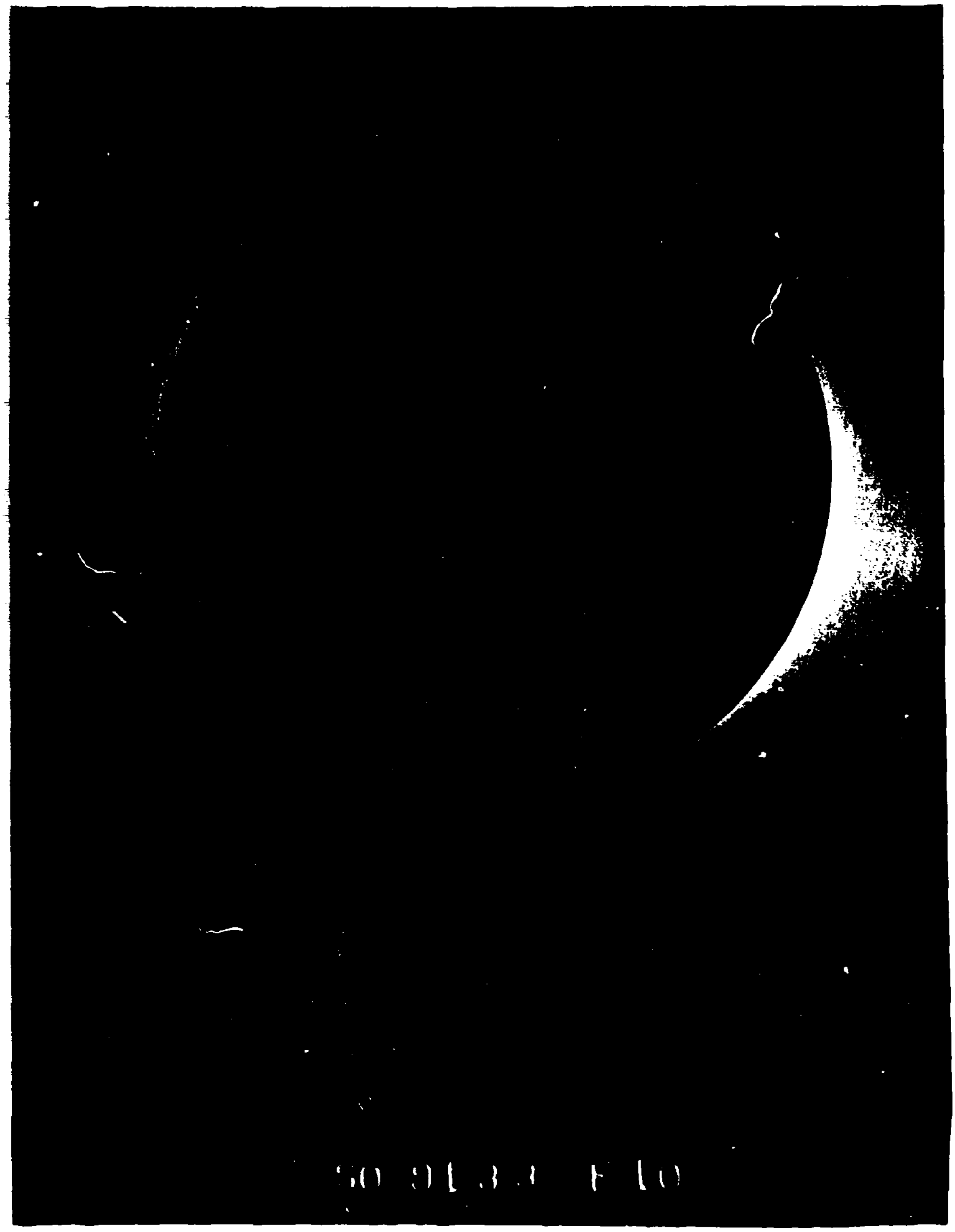
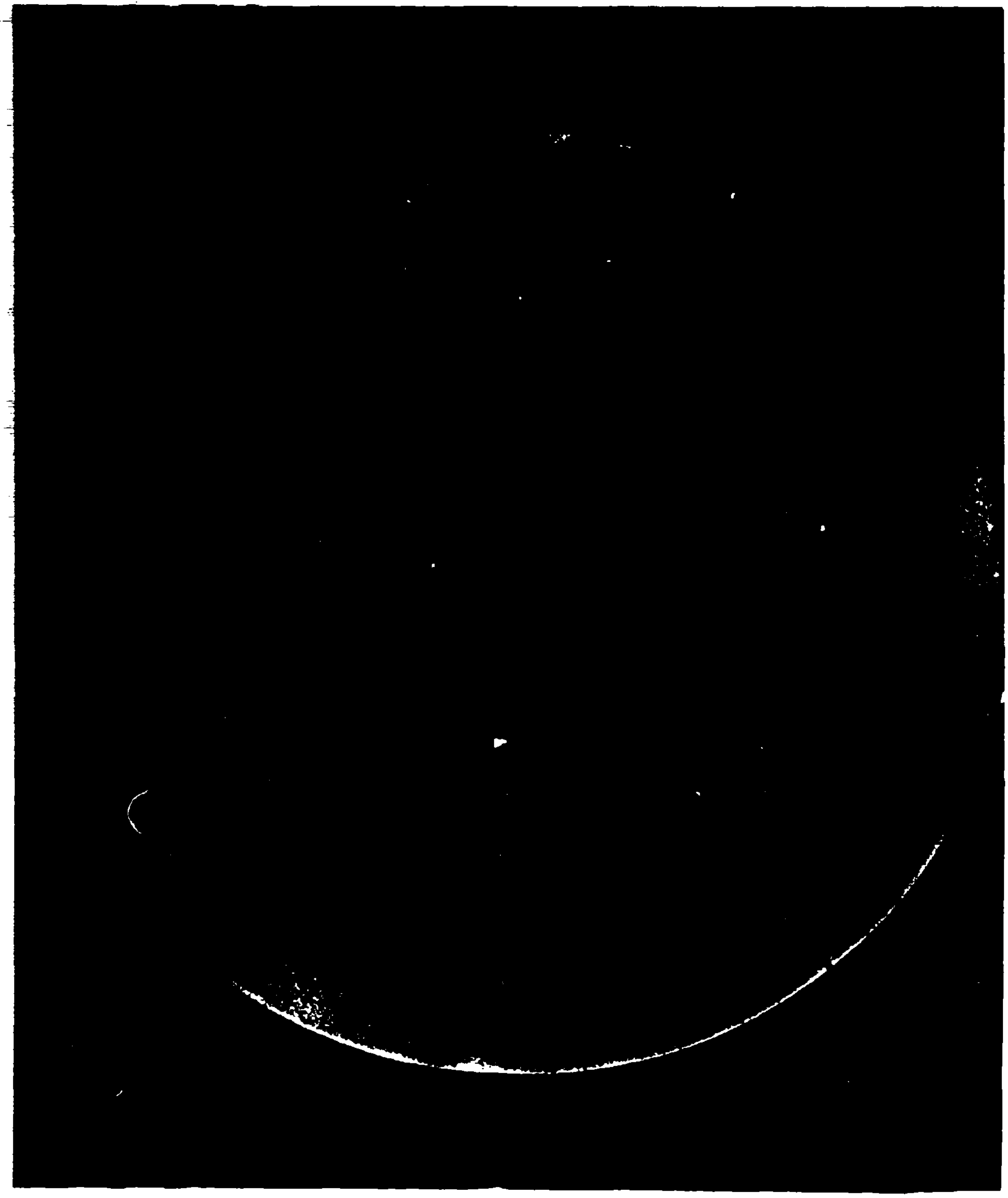


FIGURE 50 Section G12, Method "A" - Etchant 10% NaOH



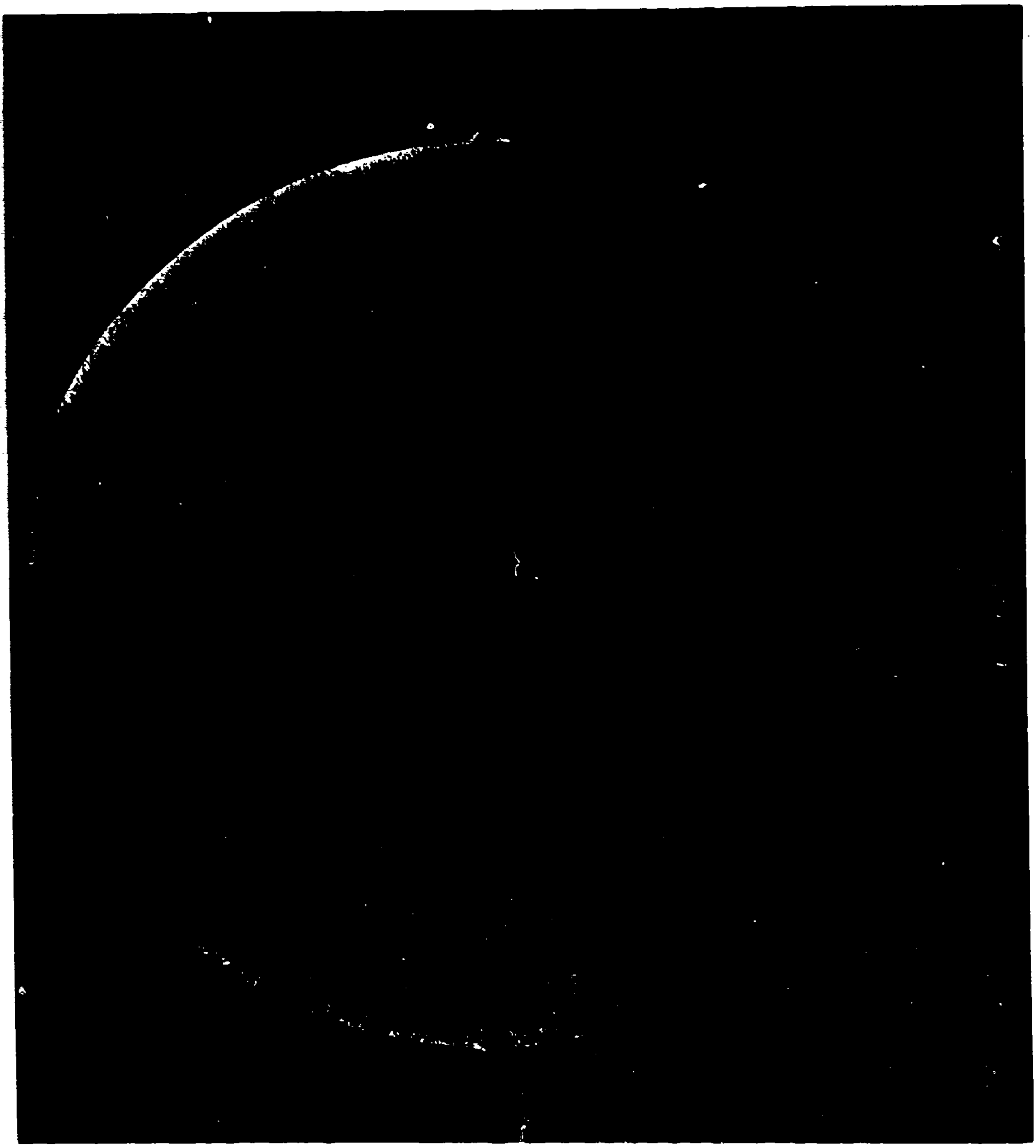


FIGURE 51 Section 312, Method "B" - Etchant 10% NaOH

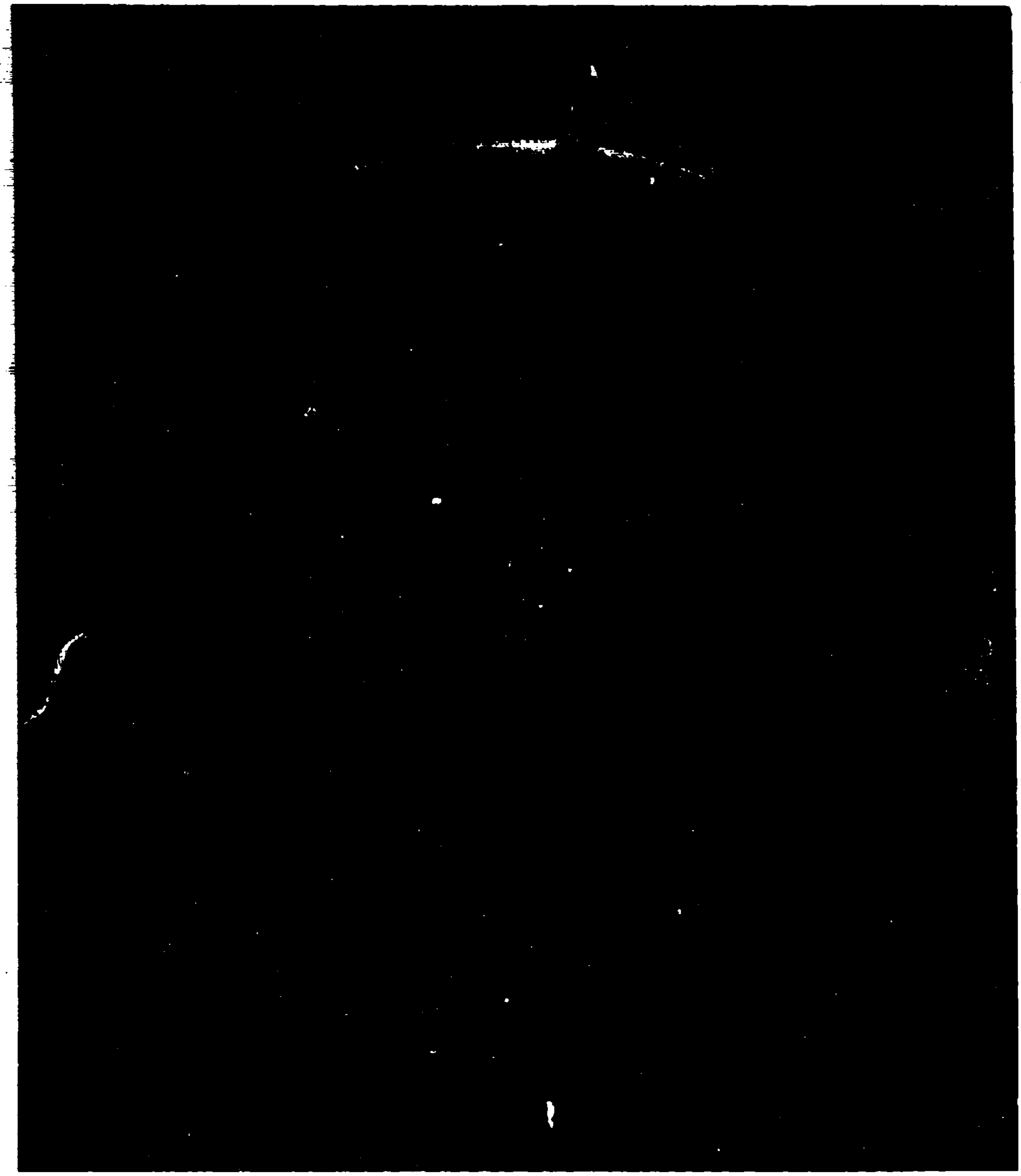


FIGURE 52 Section G12, Method 'C' - Etchant 10% NaOH

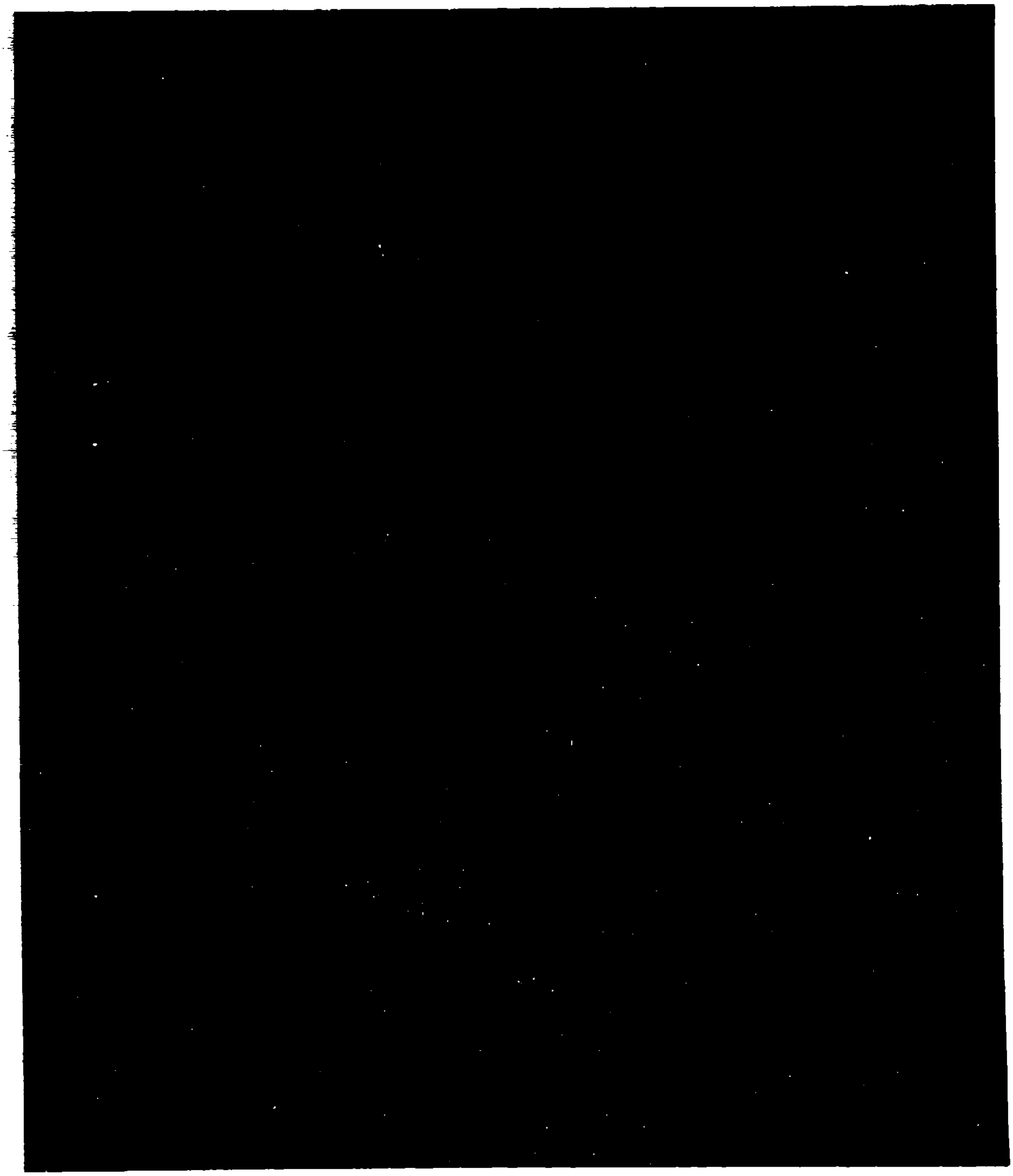


FIGURE 53 Section G12, Method "D" - Etchant 10% NaOH

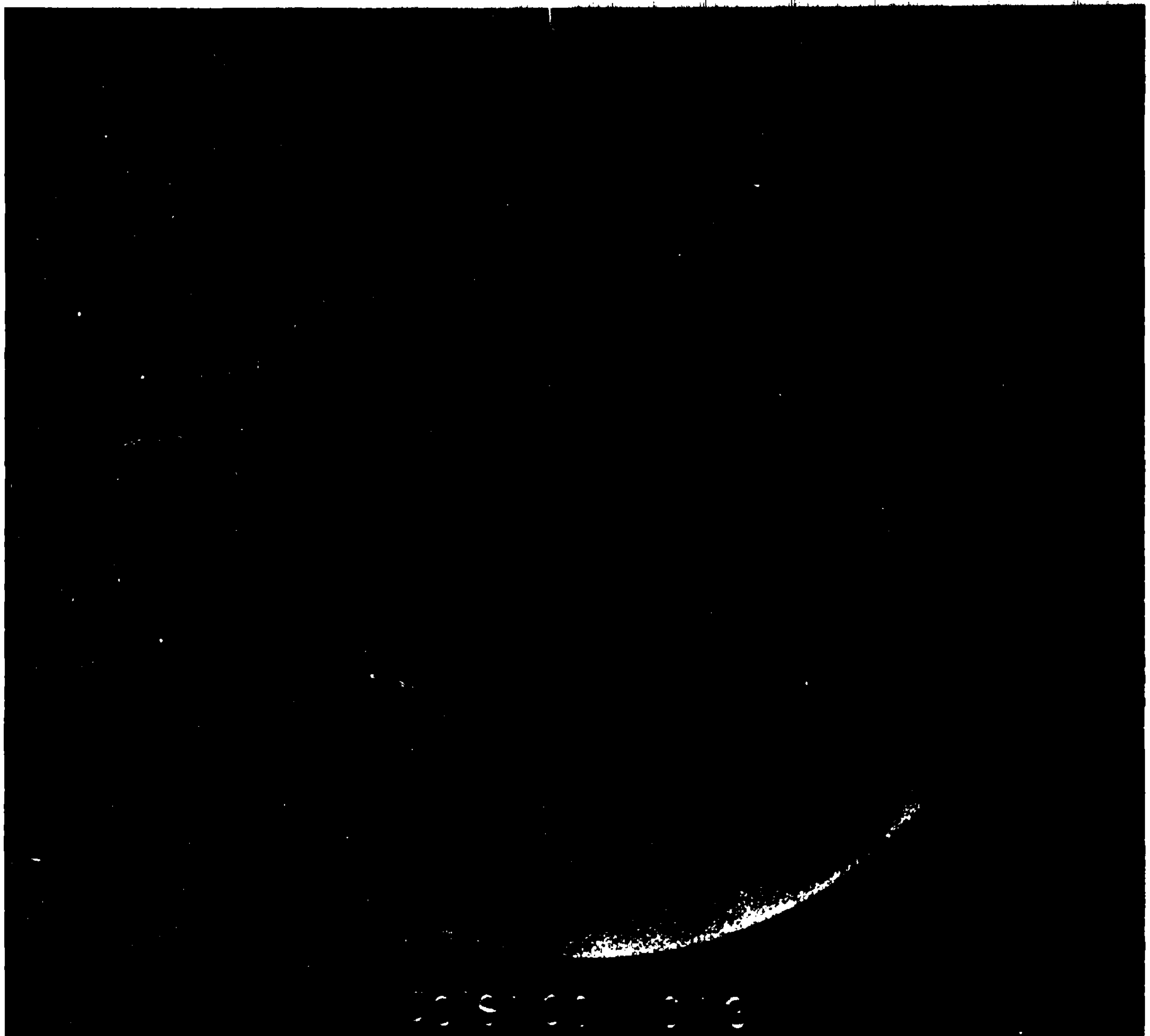


FIGURE 54 Section 313, Method "A" - Etchant 10% NaOH

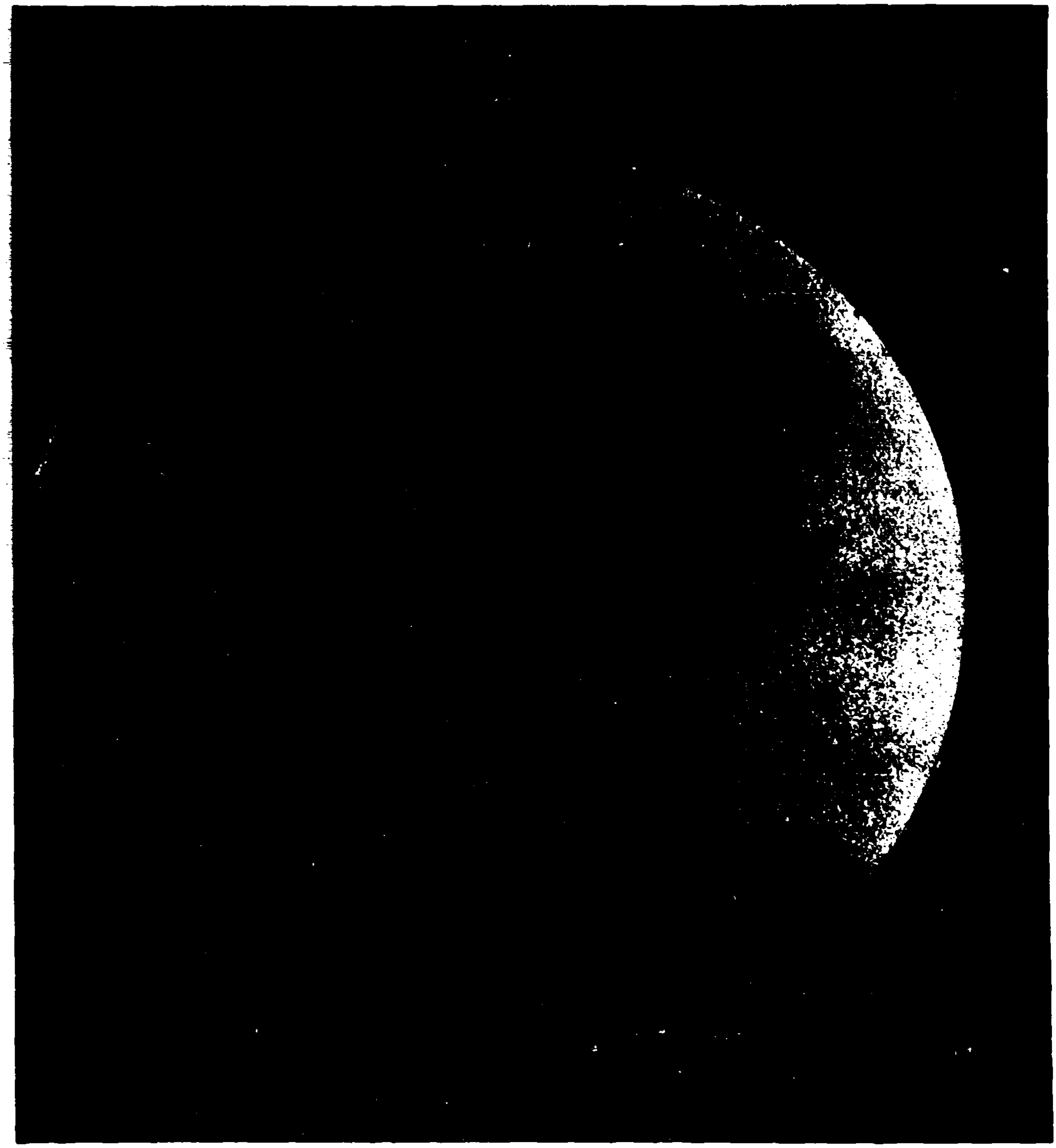


FIGURE 55 Section G13, Method "B" - Etchant 10% NaOH

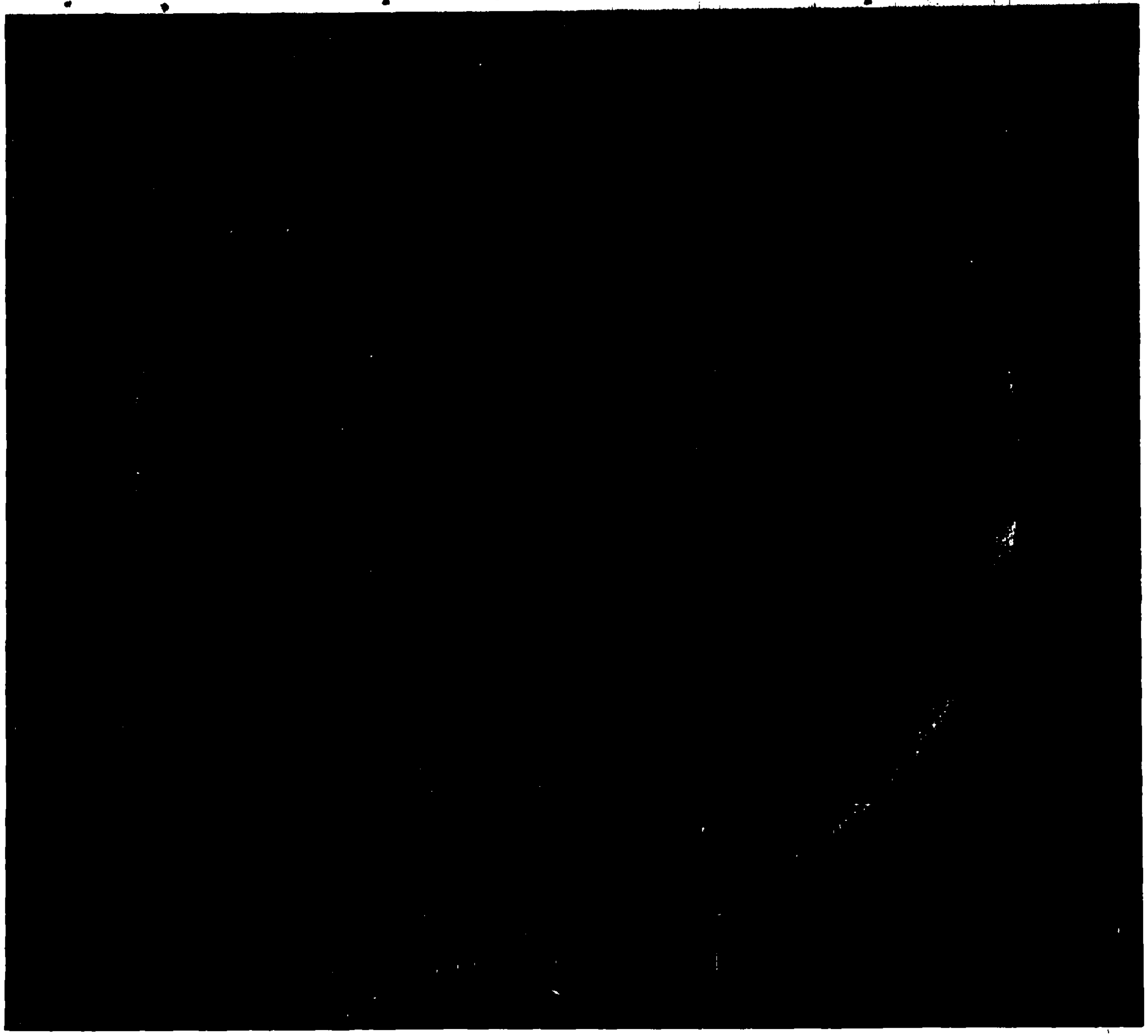


FIGURE 56 Section #13, Method "C" - Etchant 10% NaOH

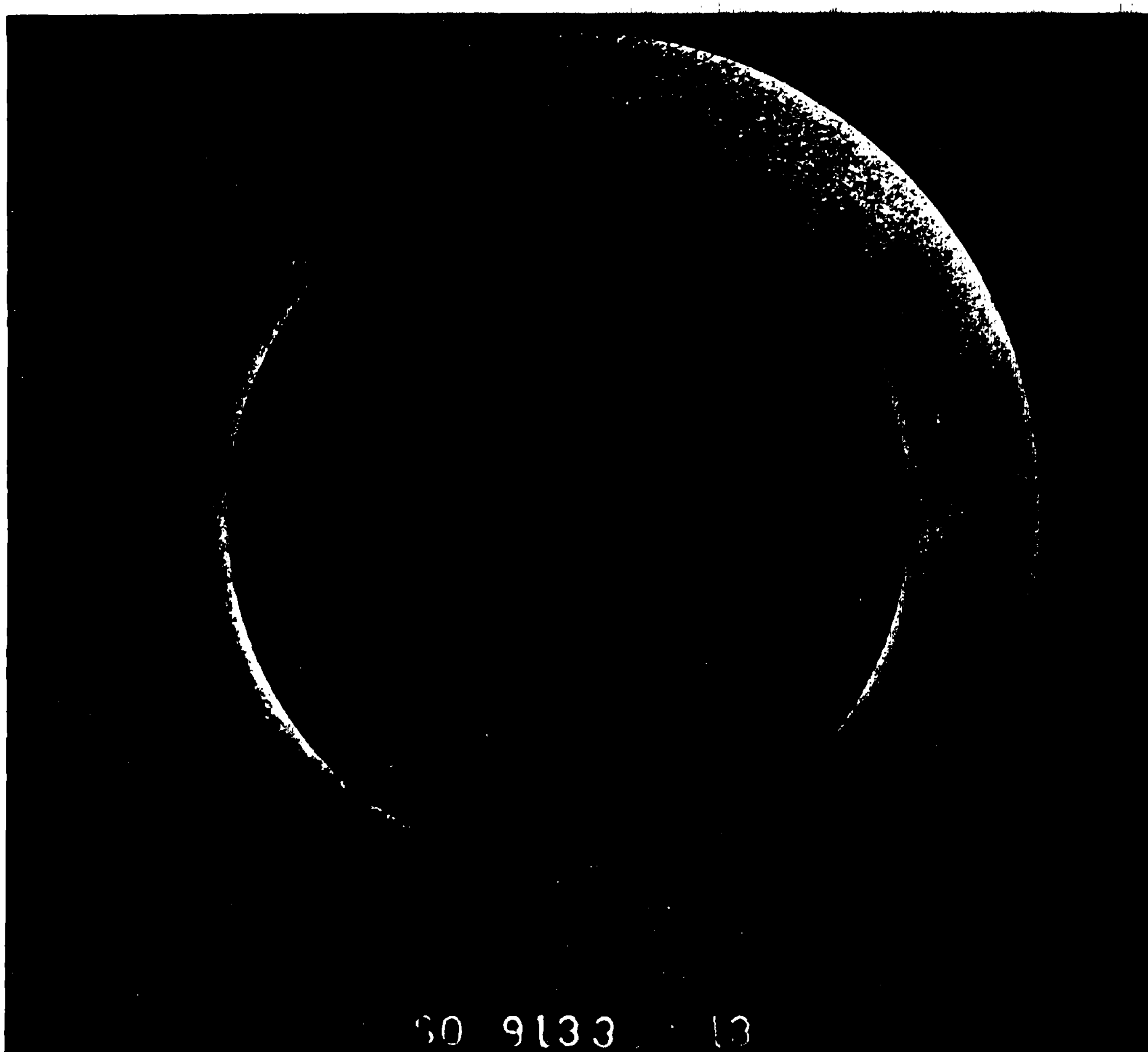


FIGURE 57 Section 313, "Method D" - Etchant 10% NaOH

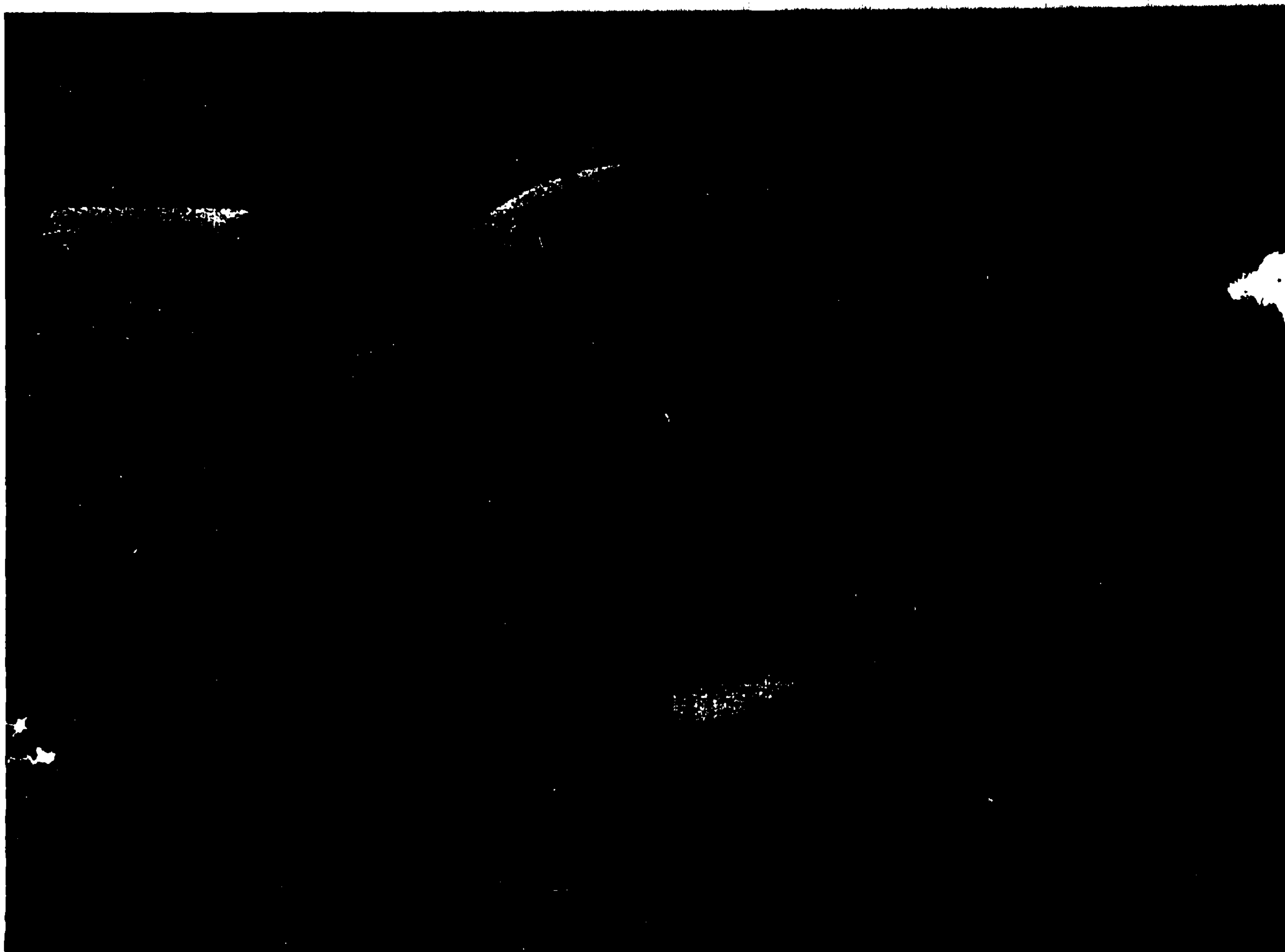


FIGURE 58 Trimmer Arm Location - Section H15, Method "A" - Etchant 10% NaOH

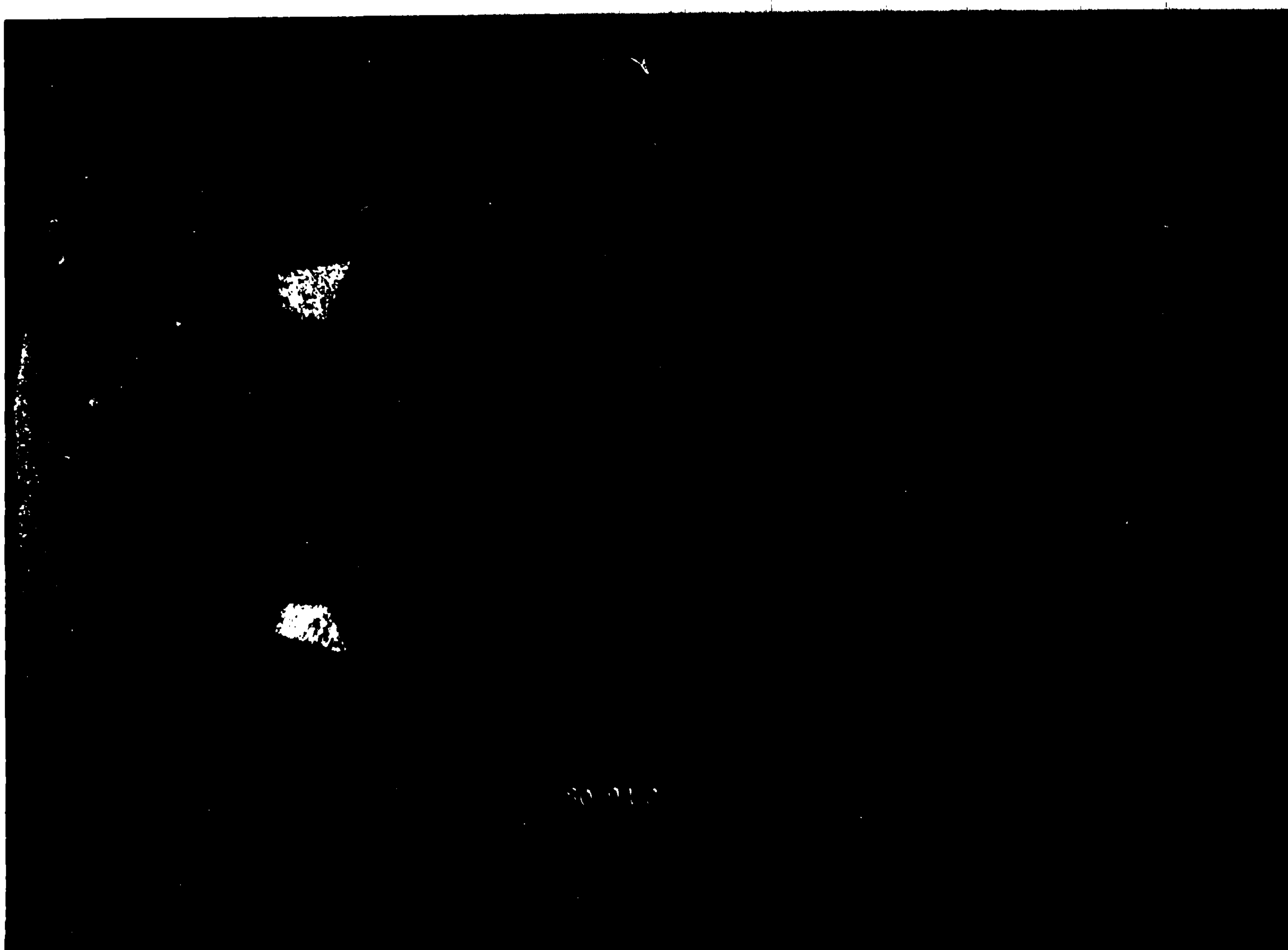


FIGURE 59 Trimmer Arm Location - Section H15, Method "B" - Etchant 10% NaOH

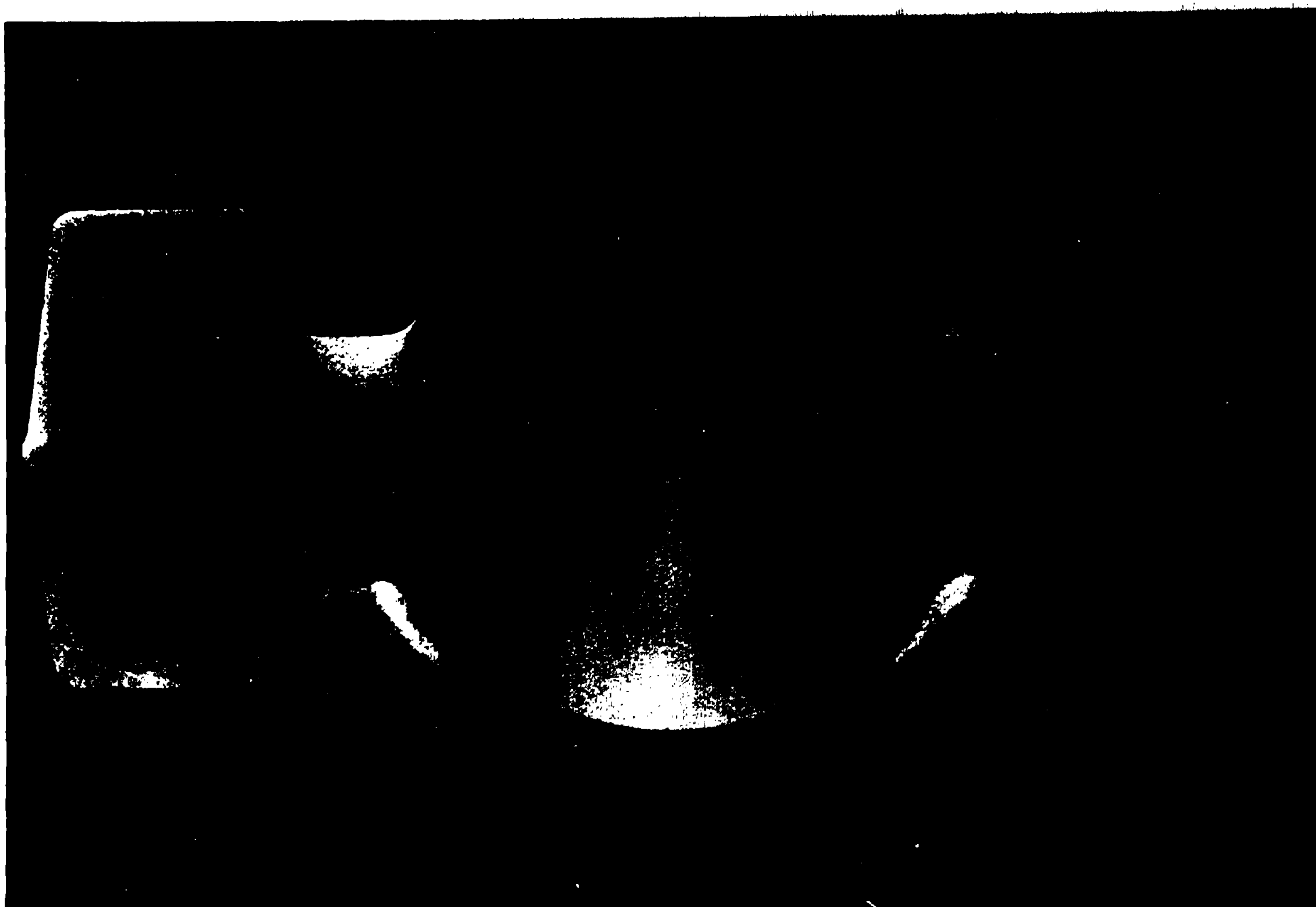


FIGURE 60 - Trimmer Arm Location - Section H15, Method "C" - Etchant 10% NaOH

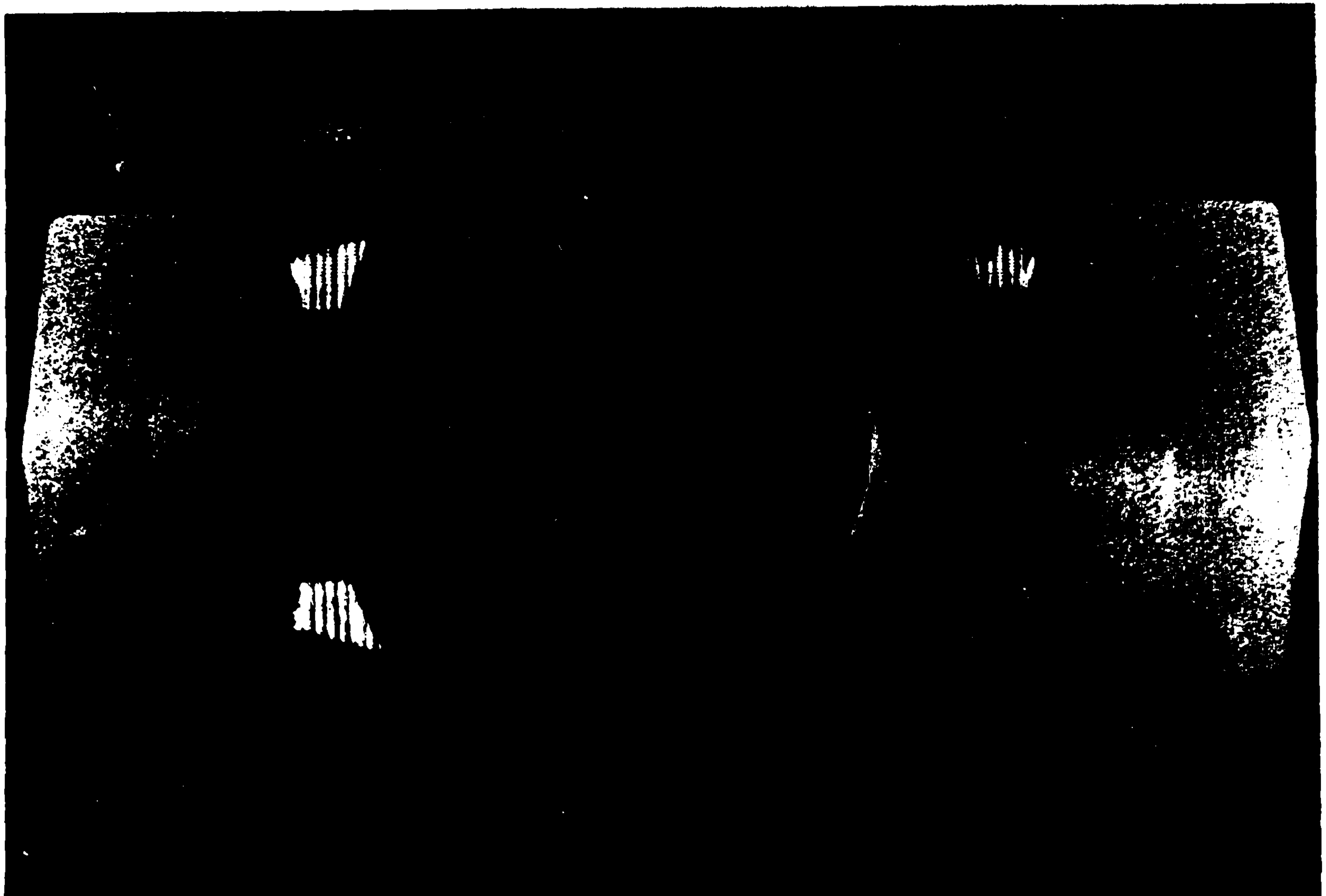


FIGURE 61 - Trimmer Arm Location - Section H15, Method "D" - Etchant 10% NaOH

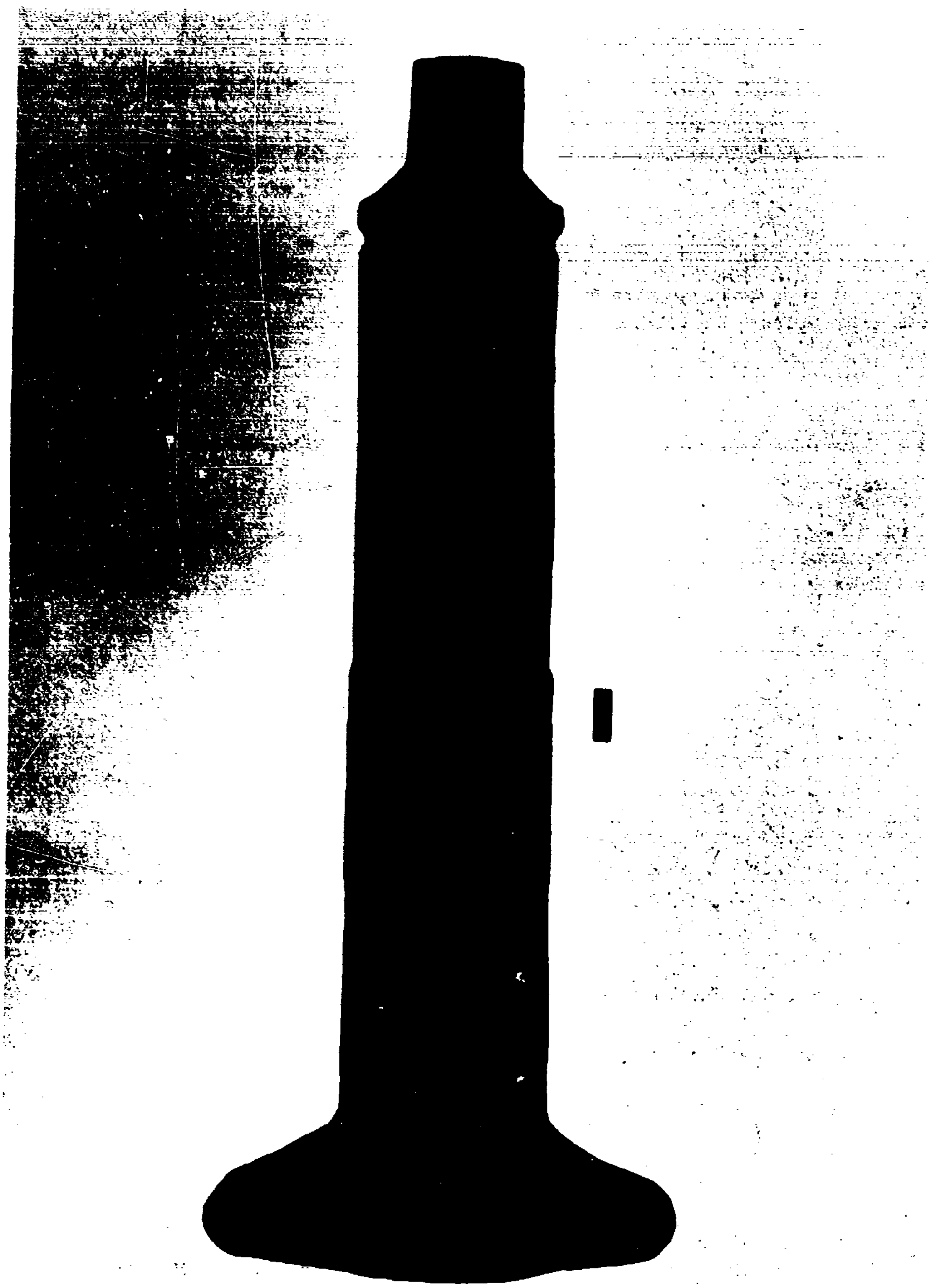


FIGURE 62 - Parting Line Grain Flow, Method "A"

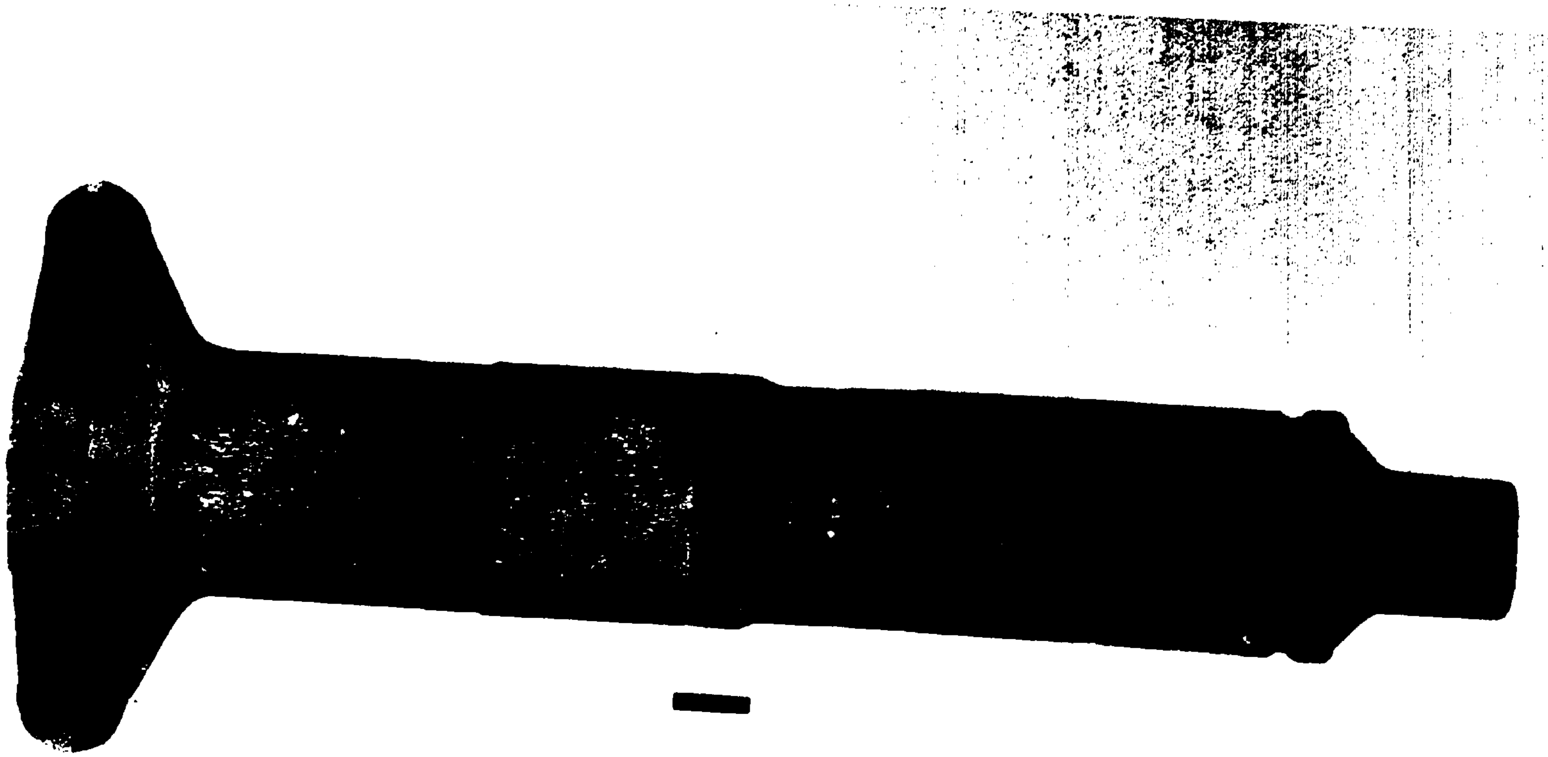


FIGURE 63 - Parting Line Grain Flow, Method "B"

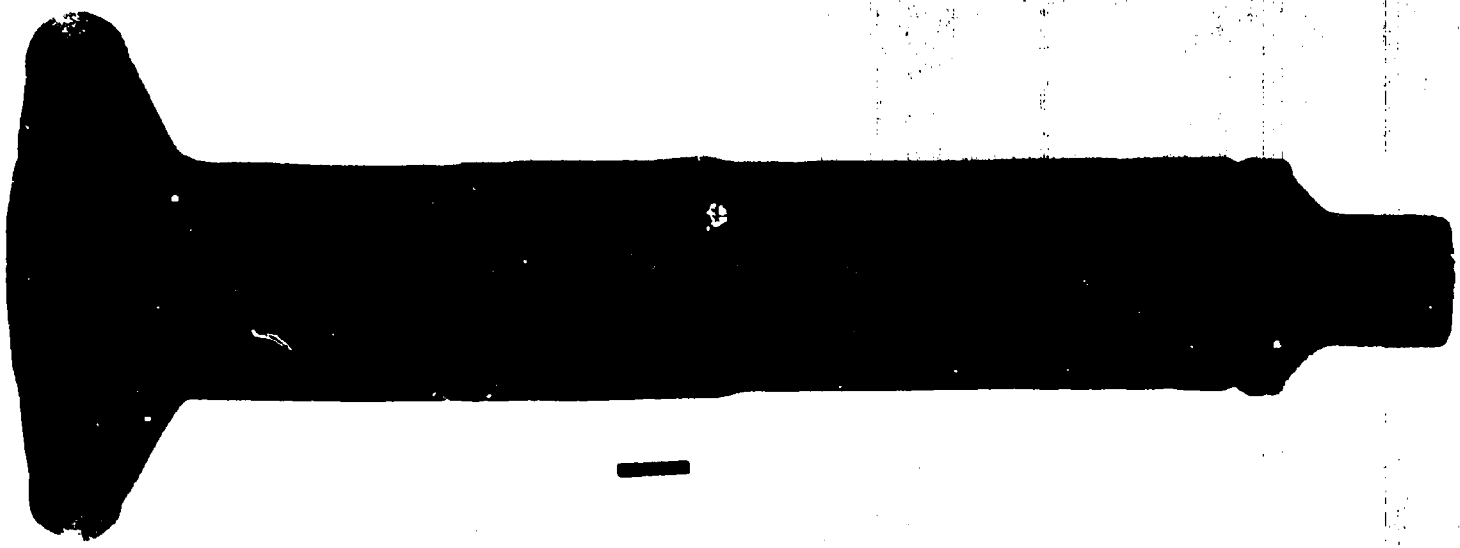


FIGURE 64 - Parting Line Grain Flow, Method "C"

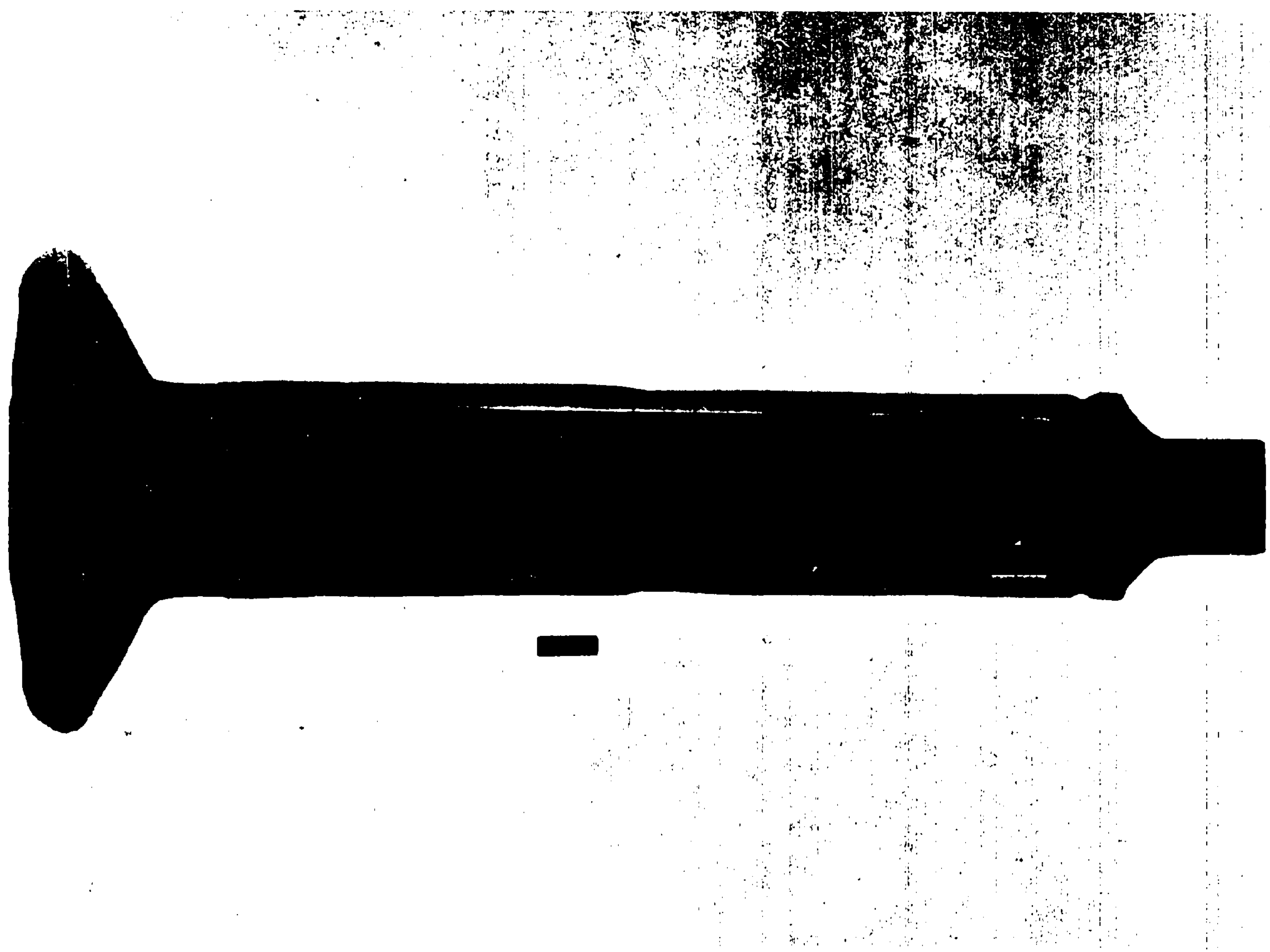


FIGURE 65 - Parting Line Grain Flow, Method "D"

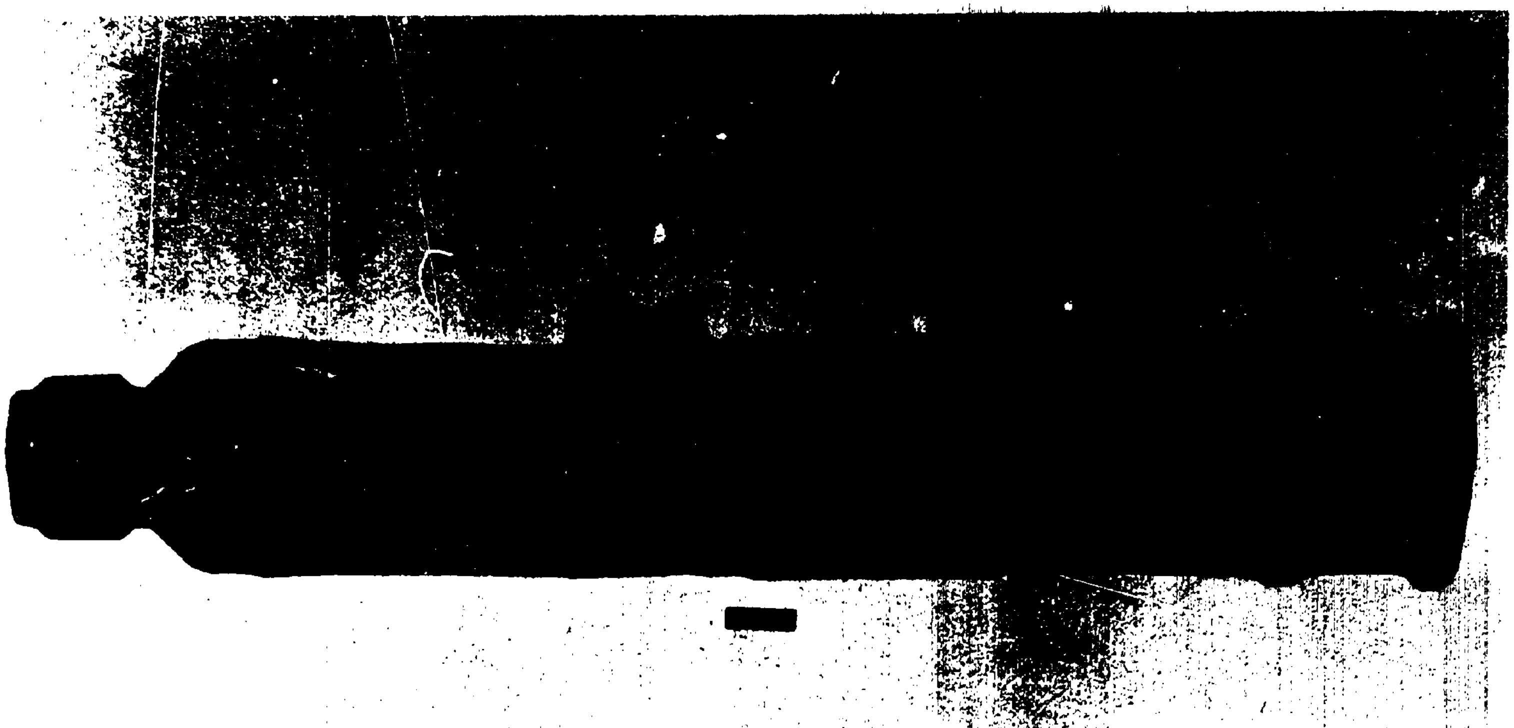


FIGURE 66 - Grain Flow Perpendicular to Parting Line, Method "A"

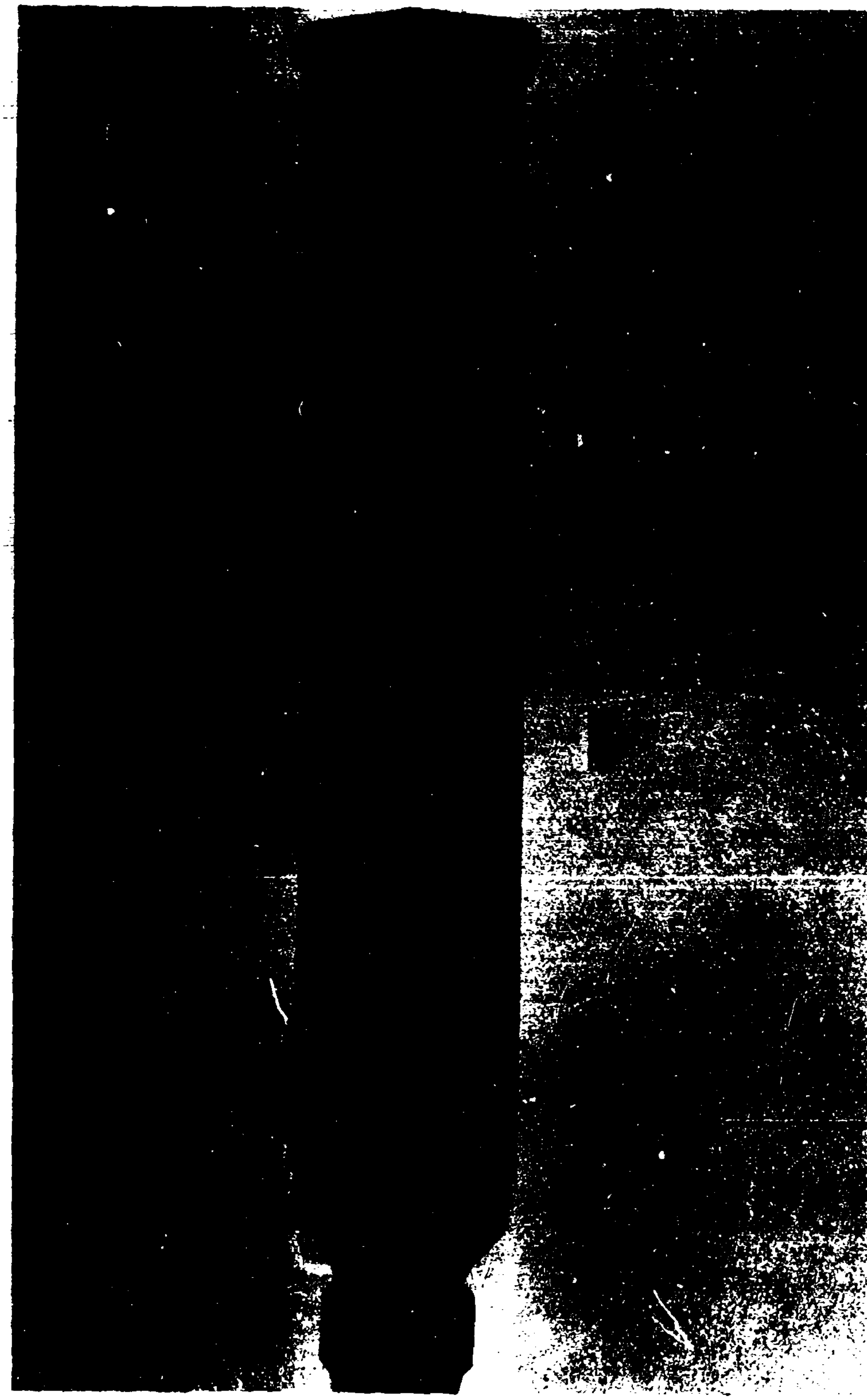


FIGURE 67 - Grain Flow Perpendicular to Parting Line, Method "B"

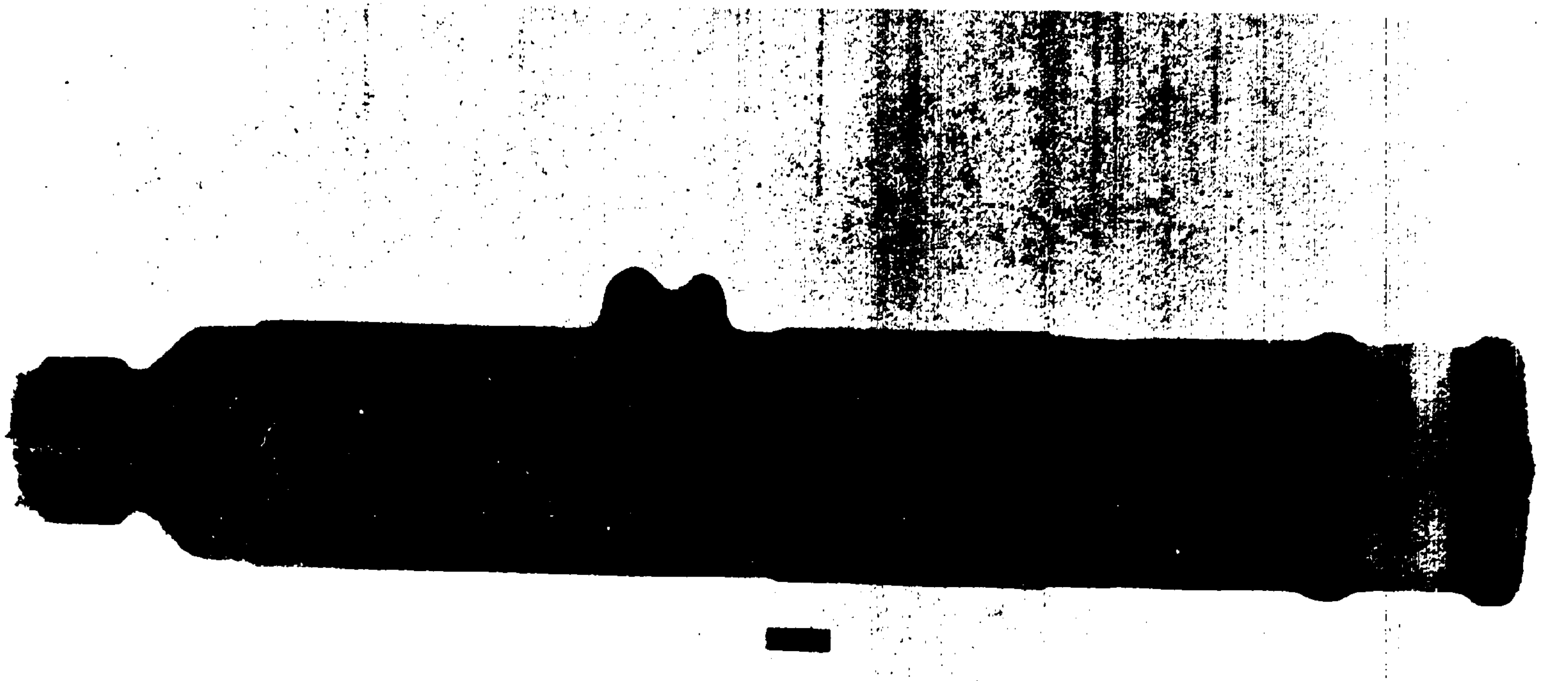


FIGURE 68 - Grain Flow Perpendicular to Parting Line, Method "C"

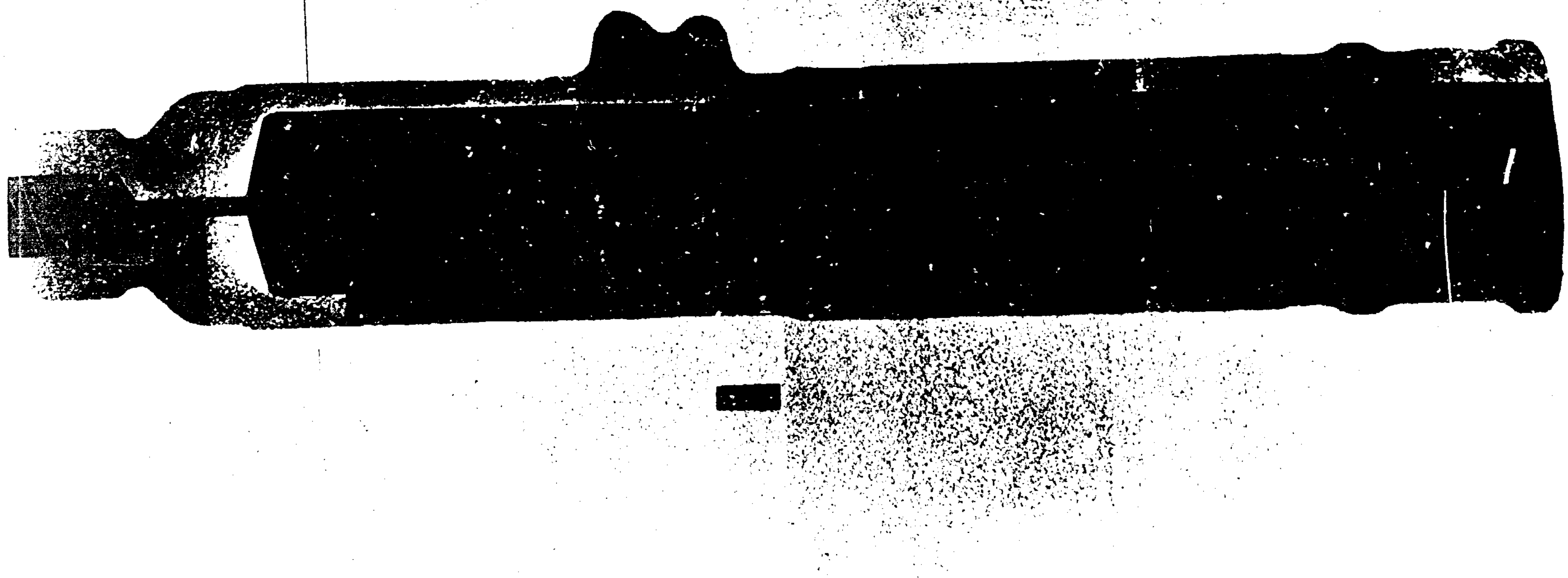
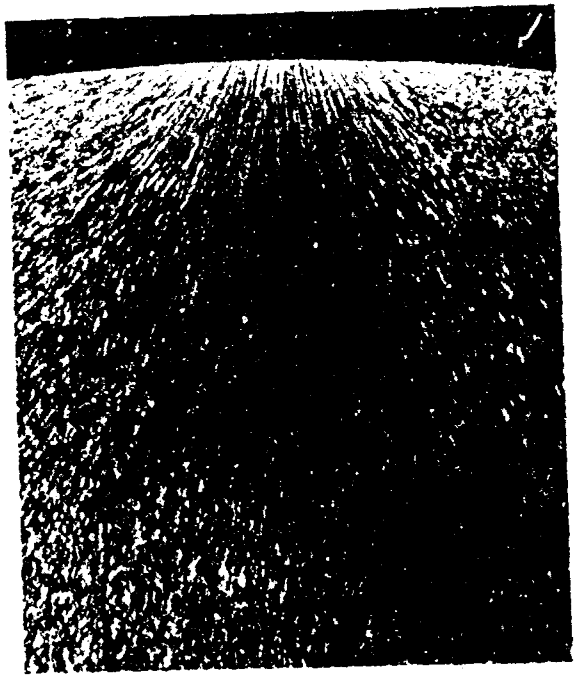
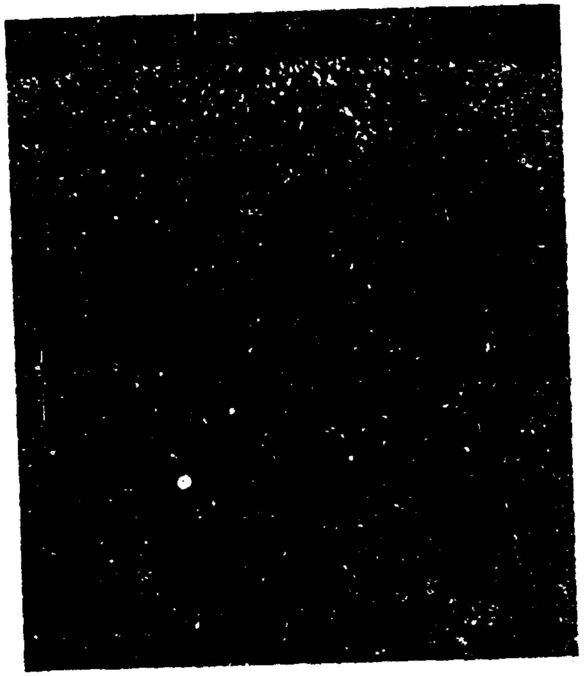


FIGURE 69 - Grain Flow Perpendicular to Parting Line, Method "D"



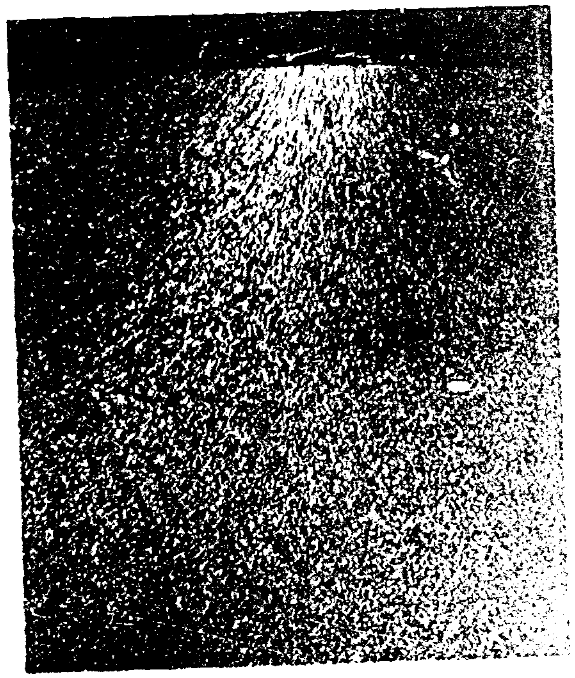
Method A

Conventional Practice



Method B

Regular Cog



Method C

Offset Cog

Figure 70. This enlarged photograph (4X) of cross sections G13 shows the severity of flashline flow in forgings produced by three different forging practices.

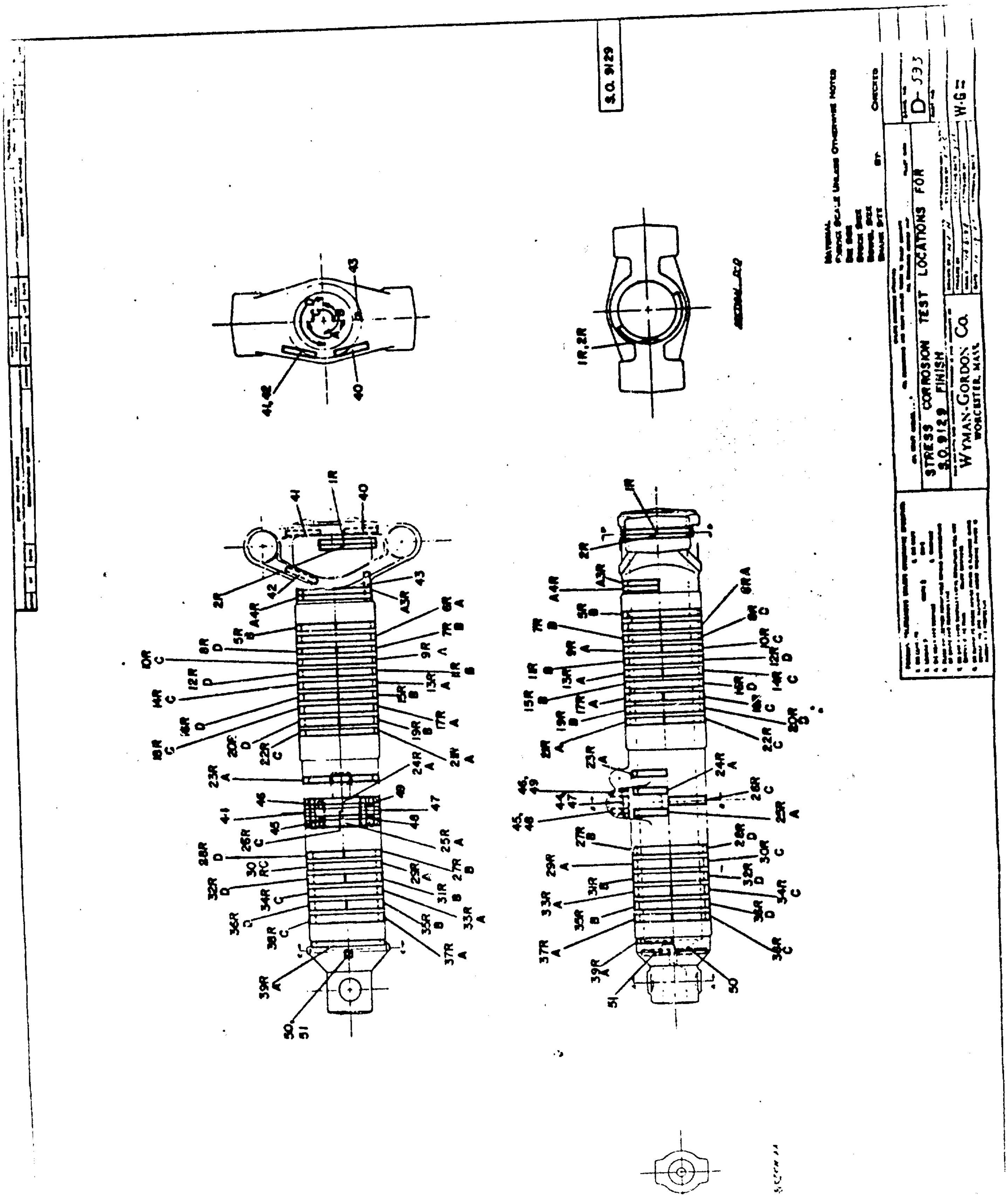

S.O. 9129
STRESS CORROSION TEST LOCATIONS FOR
S.O. 9129 FINISH
WYMAN-GORDON CO.
WORCESTER, MASS.
D-533

FIGURE 71

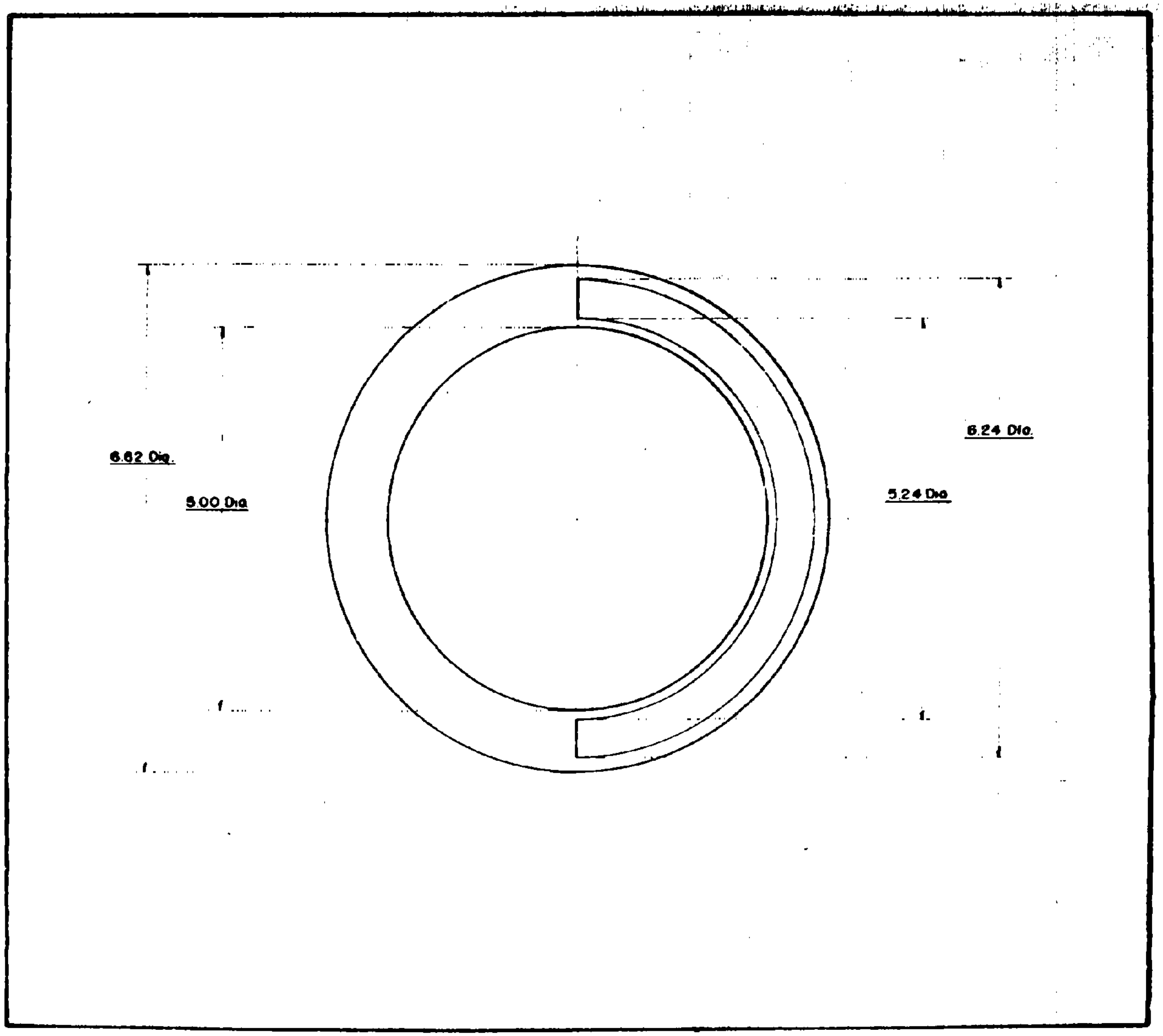


FIGURE 72 - Typical Location of Stress Corrosion Ring Test in Forging Barrel

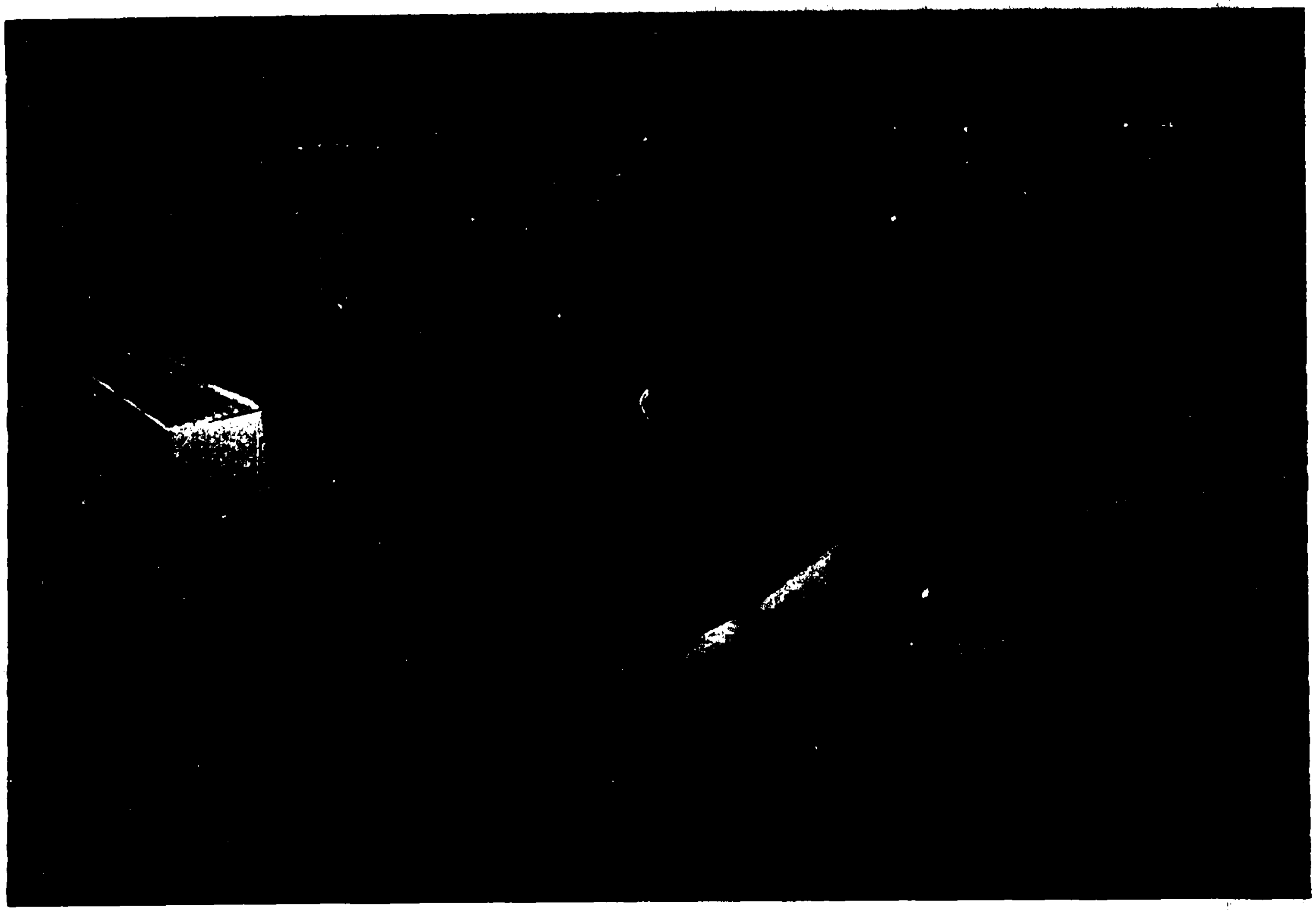


FIGURE 73 - A foil strain gage was cemented to the inside center of the test ring to determine the strain at this point vs. deflection measured from the punch marks on the side of the ring.

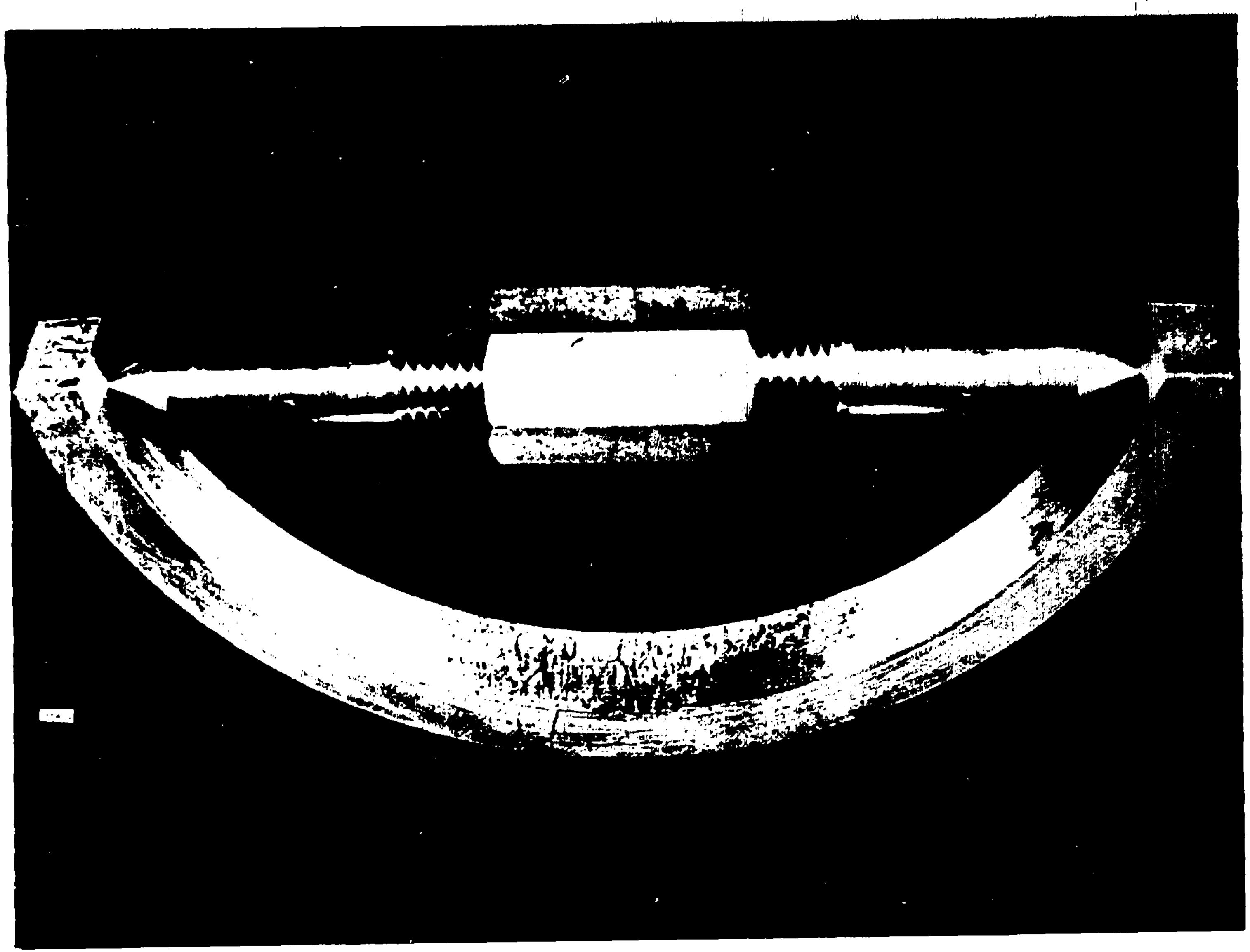


FIGURE 74 - Method of loading specimen by means of a stainless steel turnbuckle.

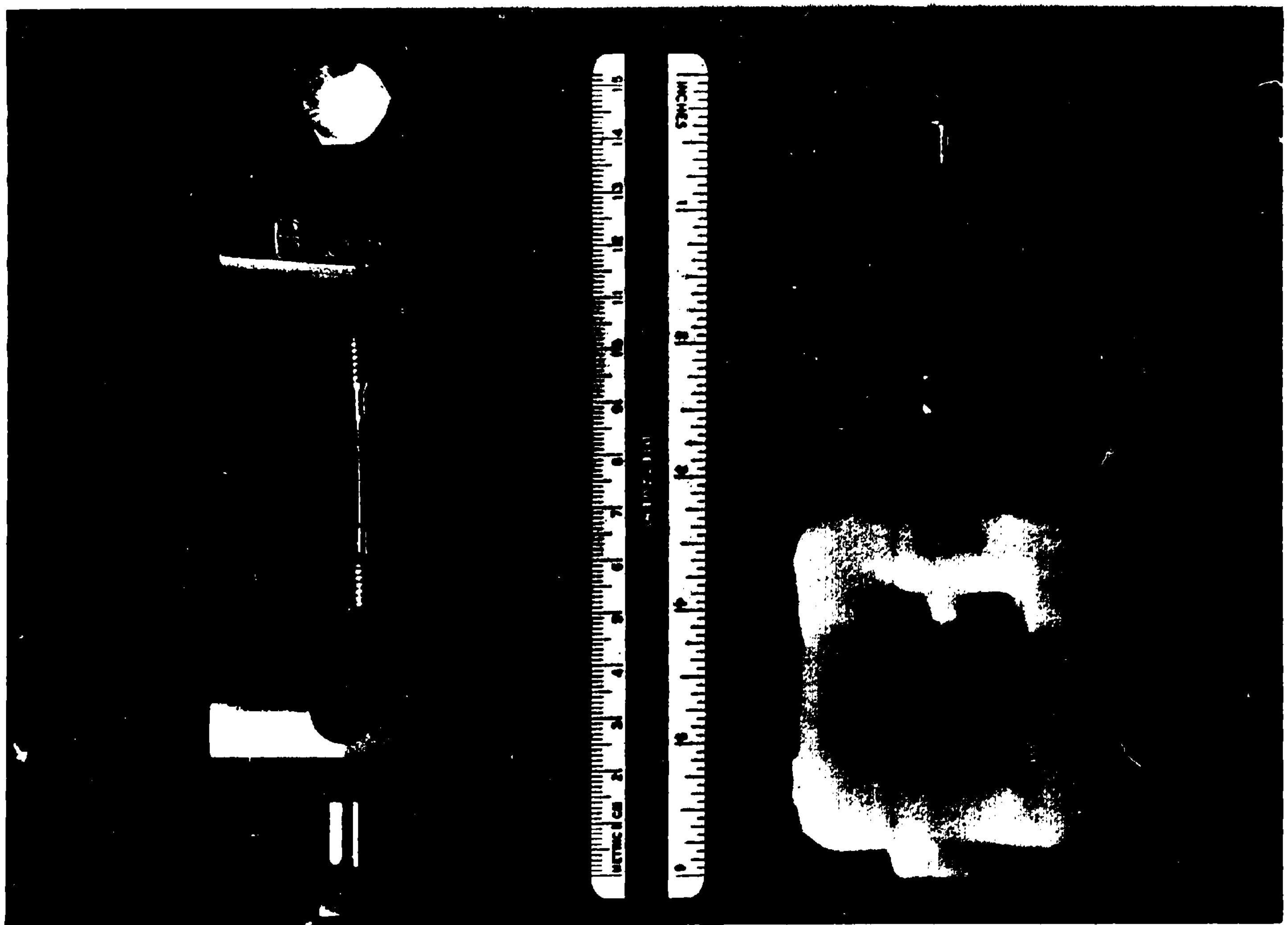
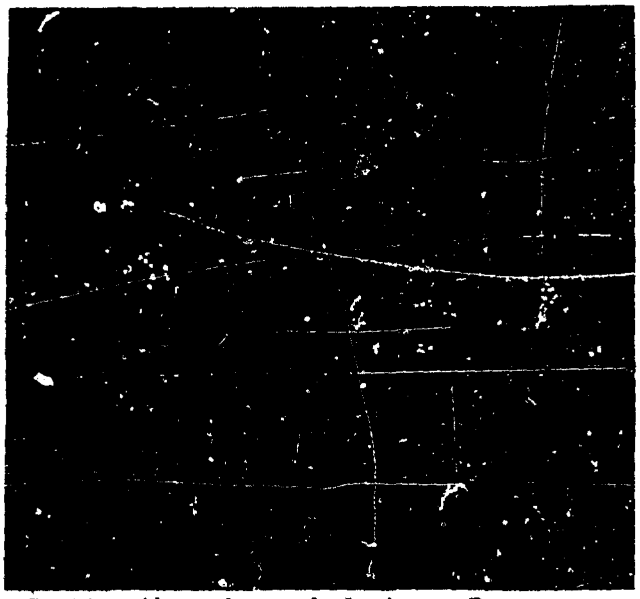
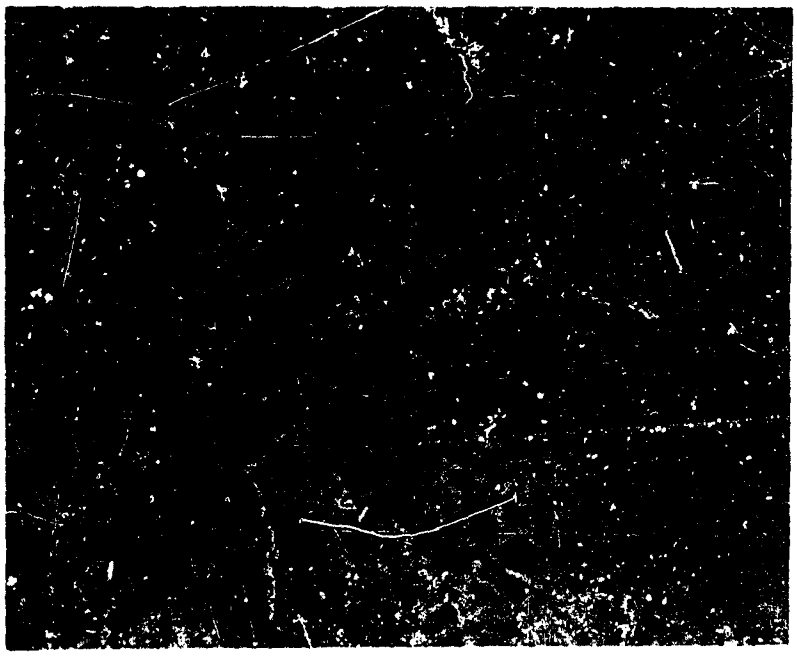


FIGURE 75 - Stress Corrosion Tensile Round & Test Frame. Stressing frame and the stress corrosion tensile rounds are shown. After stressing, the frame is coated with a parraffin 10% polyethylene mixture.

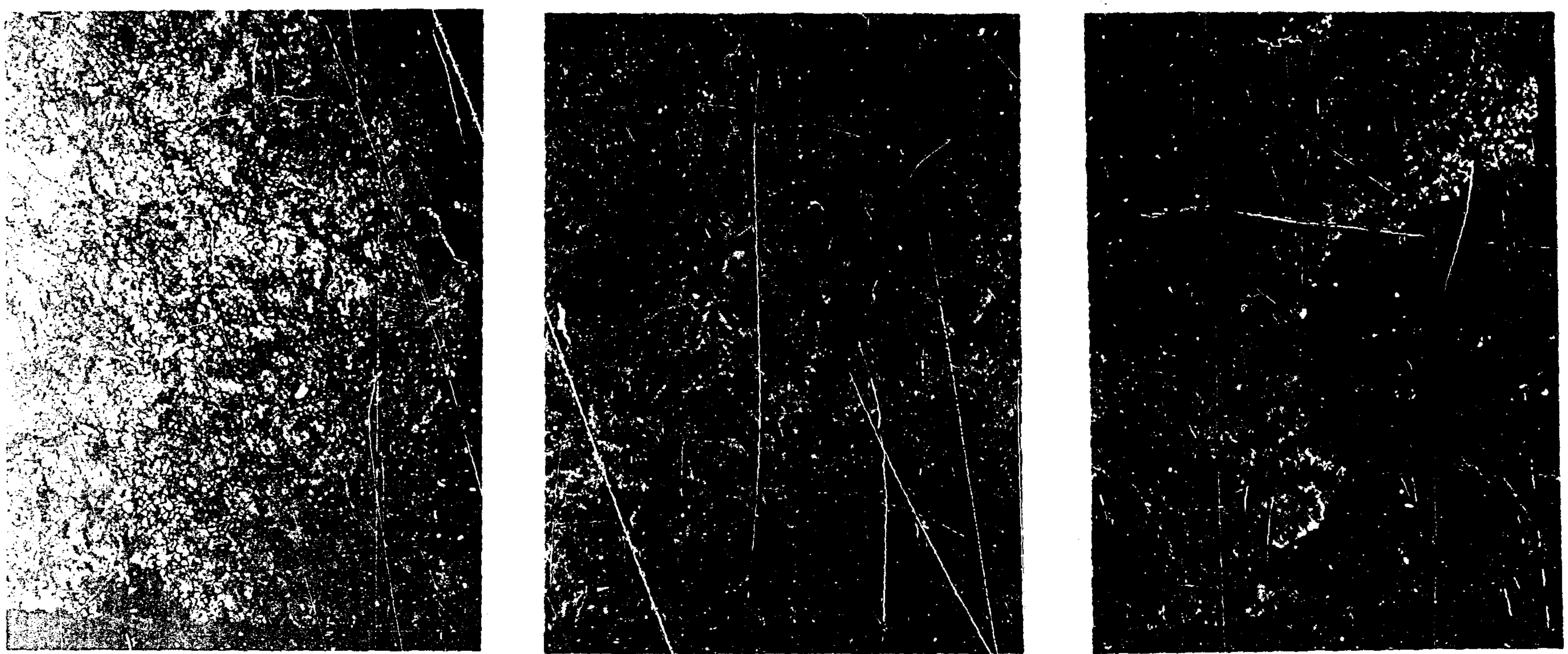


Section through cracked ring. Bore surface is on the Left.



Showing Start of Stress Corrosion Crack at the Bore Surface.
Etchant - Modified Keller's 100X

Figure 76. Stress Corrosion Specimen RC39 Which Failed in 26 Days at 45 KSI.



Method A

Stress Corrosion ring test life of 15 days at 30 KSI.

Method B

Stress corrosion ring test life 12 days at 30 KSI.

Method C

Stress corrosion ring test life 16 days at 30 KSI.

Figure 77. Microstructures of ring tests 23R from Methods A, B and C. These tests were located directly below the single boss in the central lug area and failed in this location. Microspecimens were cut and polished on a plane perpendicular to the forging longitudinal axis. The bottom of each photograph represents the bore surface. Etchant - Modified Keller's. All photos 100X.

Method A

Test ran 30 days without failure.

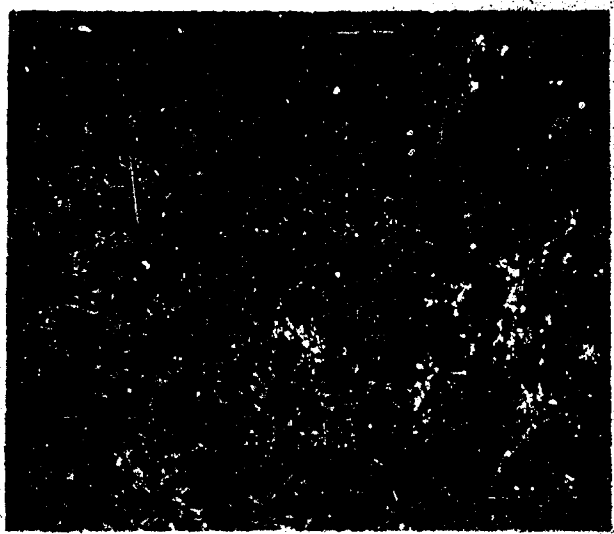
Method B

Test ran 12 days at 30 KSI.

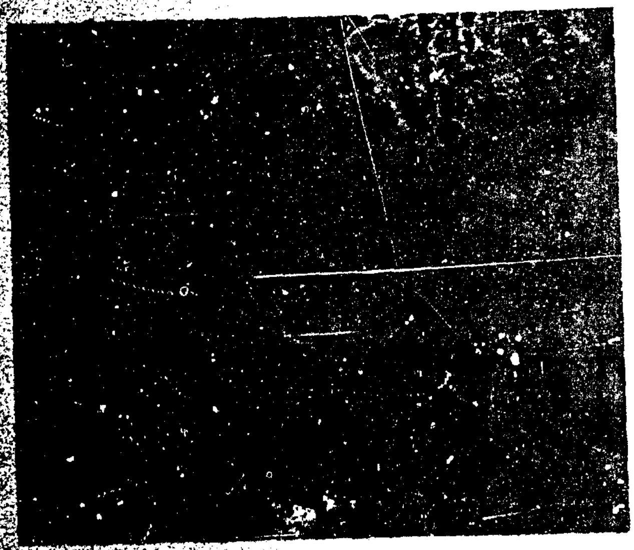
Method C

Test ran 13 days at 30 KSI and failed.

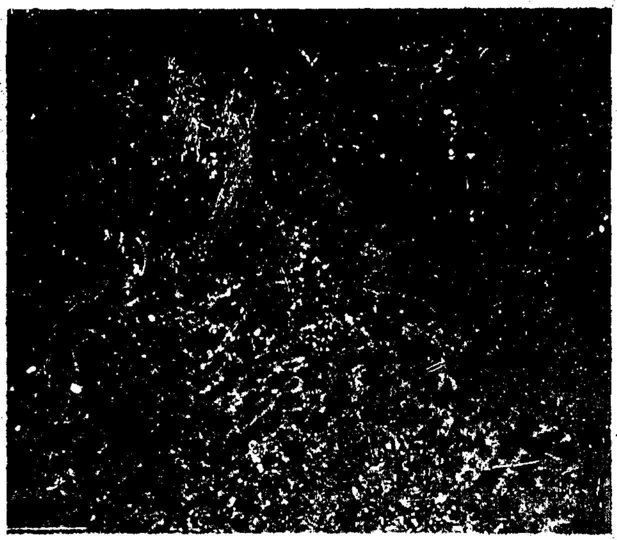
Figure 78. Structure of ring tests 24R, Methods A, B & C. This test location is under the double boss of the central lug area. All of the tests broke off center beneath one of the double bosses. Microspecimens were polished on a plane perpendicular to the forging longitudinal axis. The bottom of each photograph shows the bore inner surface. Etchant - Modified Keller's. All photos 100X.



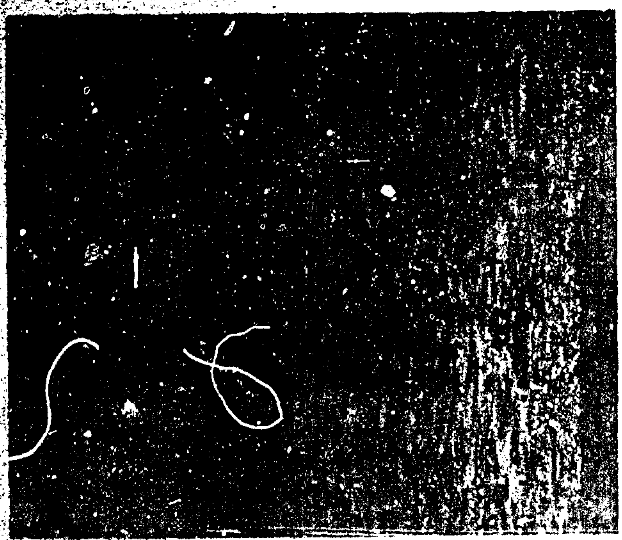
Method A Test Ran 28 Days at 30 KSI.



Method B Test Ran 30 Days Without Failure at 30 KSI.



Method C Test Ran 12 Days at 30 KSI.



Method D Test Ran 30 Days Without Failure at 30 KSI.

Figure 79. Stress corrosion ring tests from the 26R location of the four different manufacturing methods. The plane in the picture is perpendicular to the longitudinal axis of the forging. The right hand edge of each photograph is the interior bore surface. All were etched in Modified Keller's and photographed at 100X.

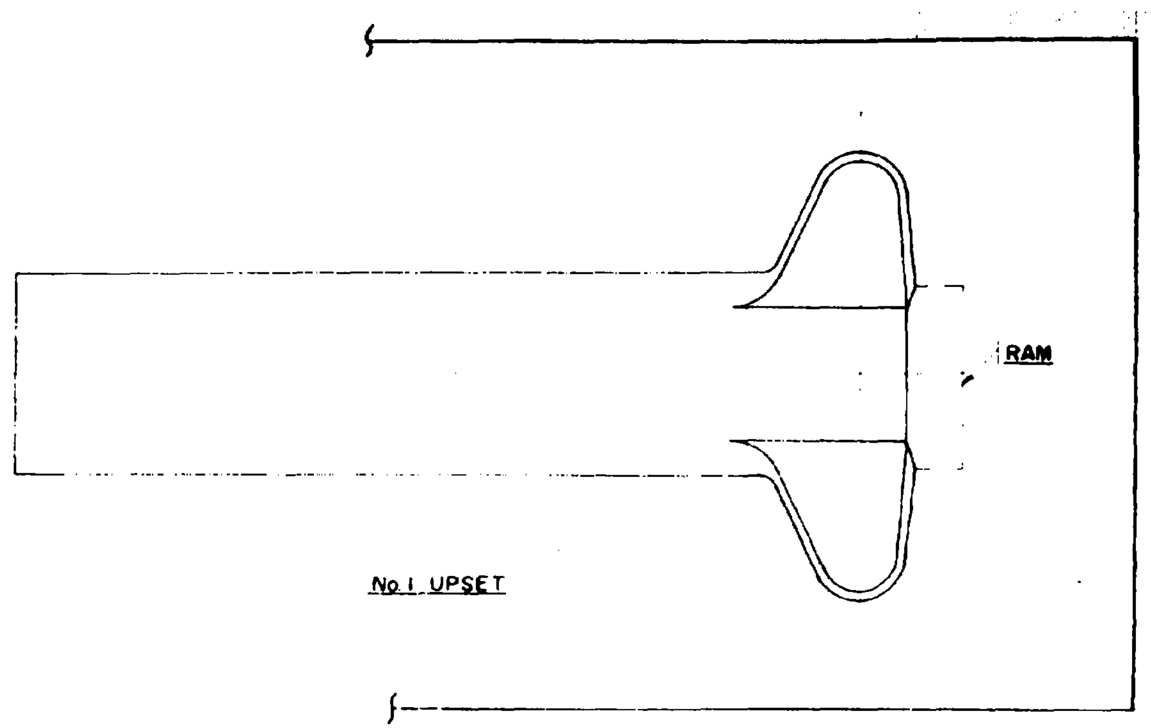


FIGURE 20 - Horizontal Controlled Upset

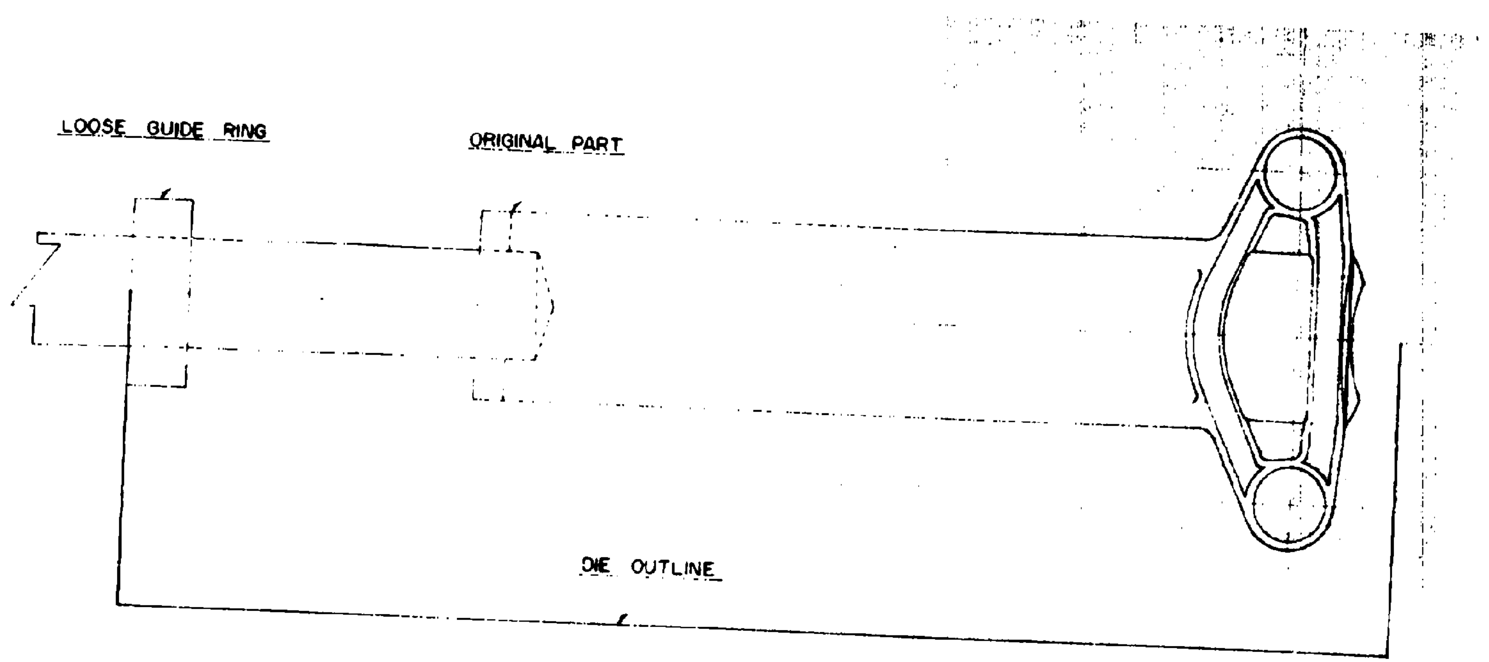


FIGURE 81 - Closed Die Forging Operation

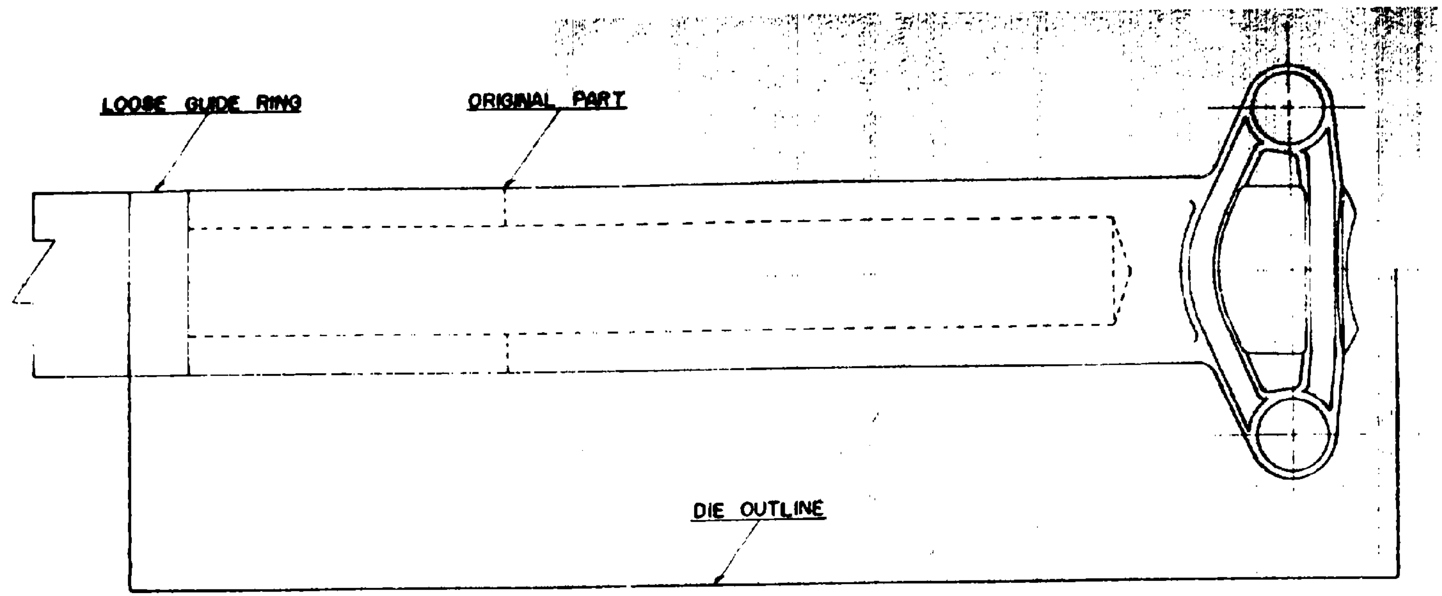


FIGURE 82 - Back Extrusion Operation

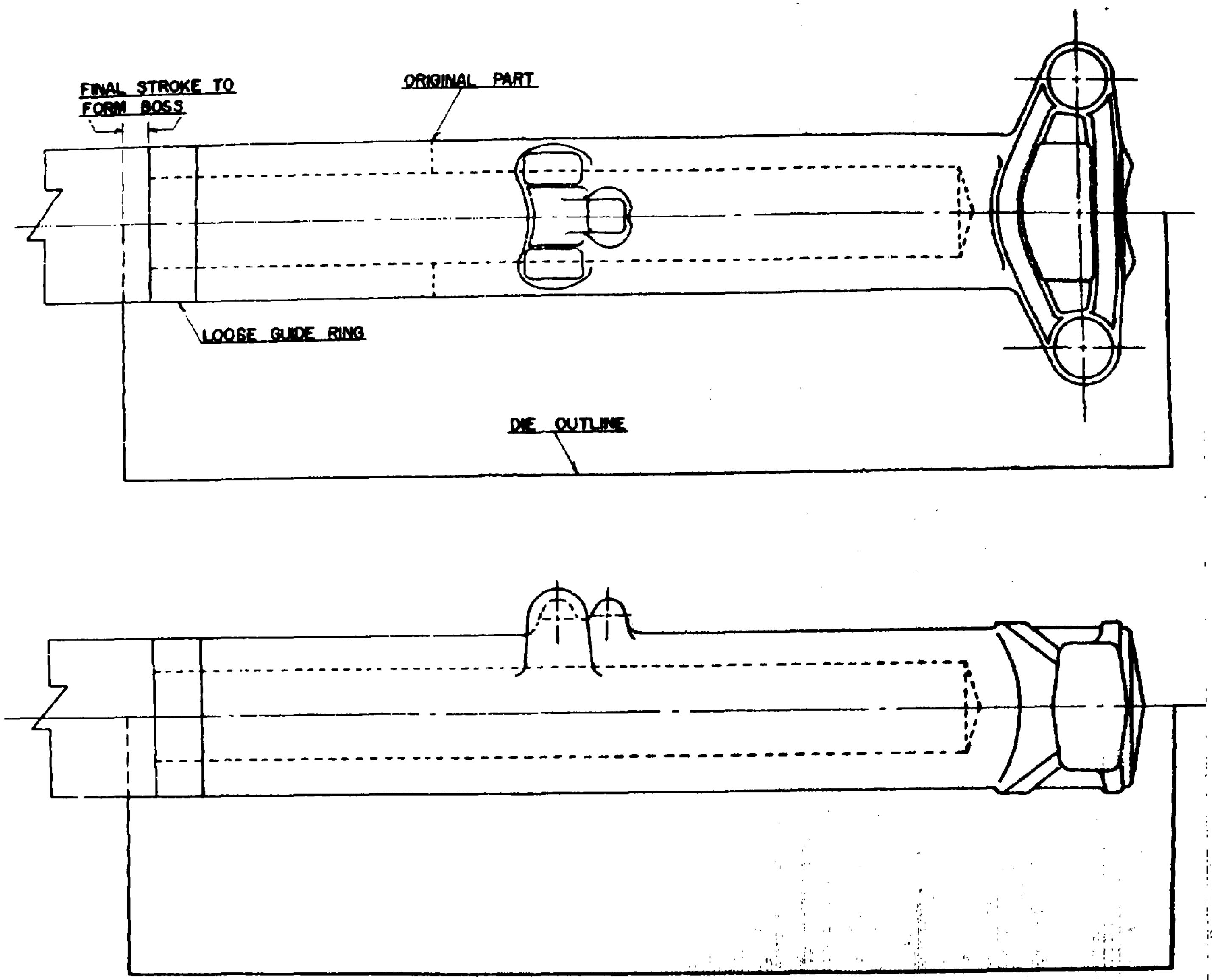


FIGURE 83 - Upset Operation

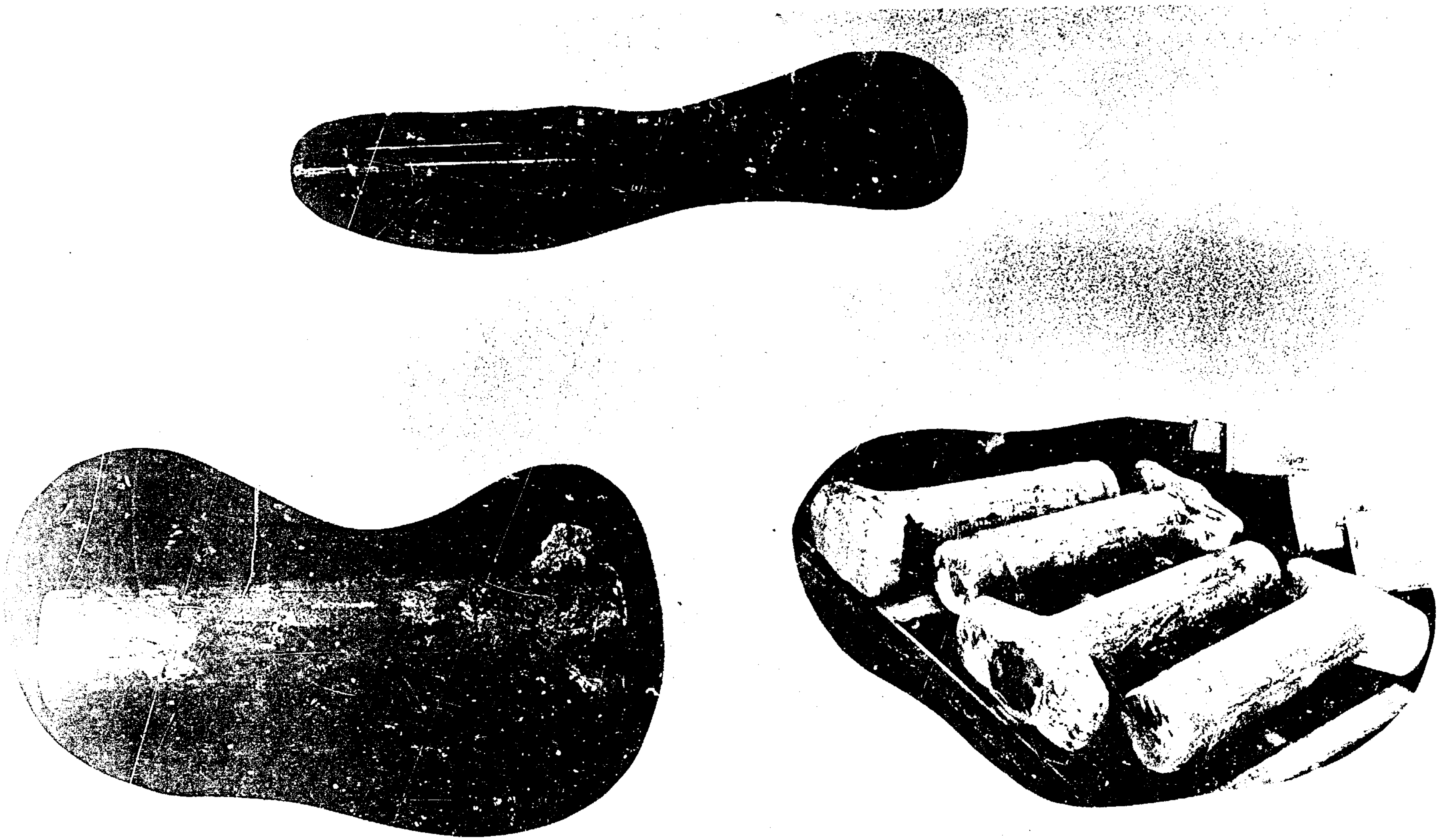


FIGURE 84 - Rolled Stock & No. 1 Upset Pieces - S/N's 1, 2, 8 & 9

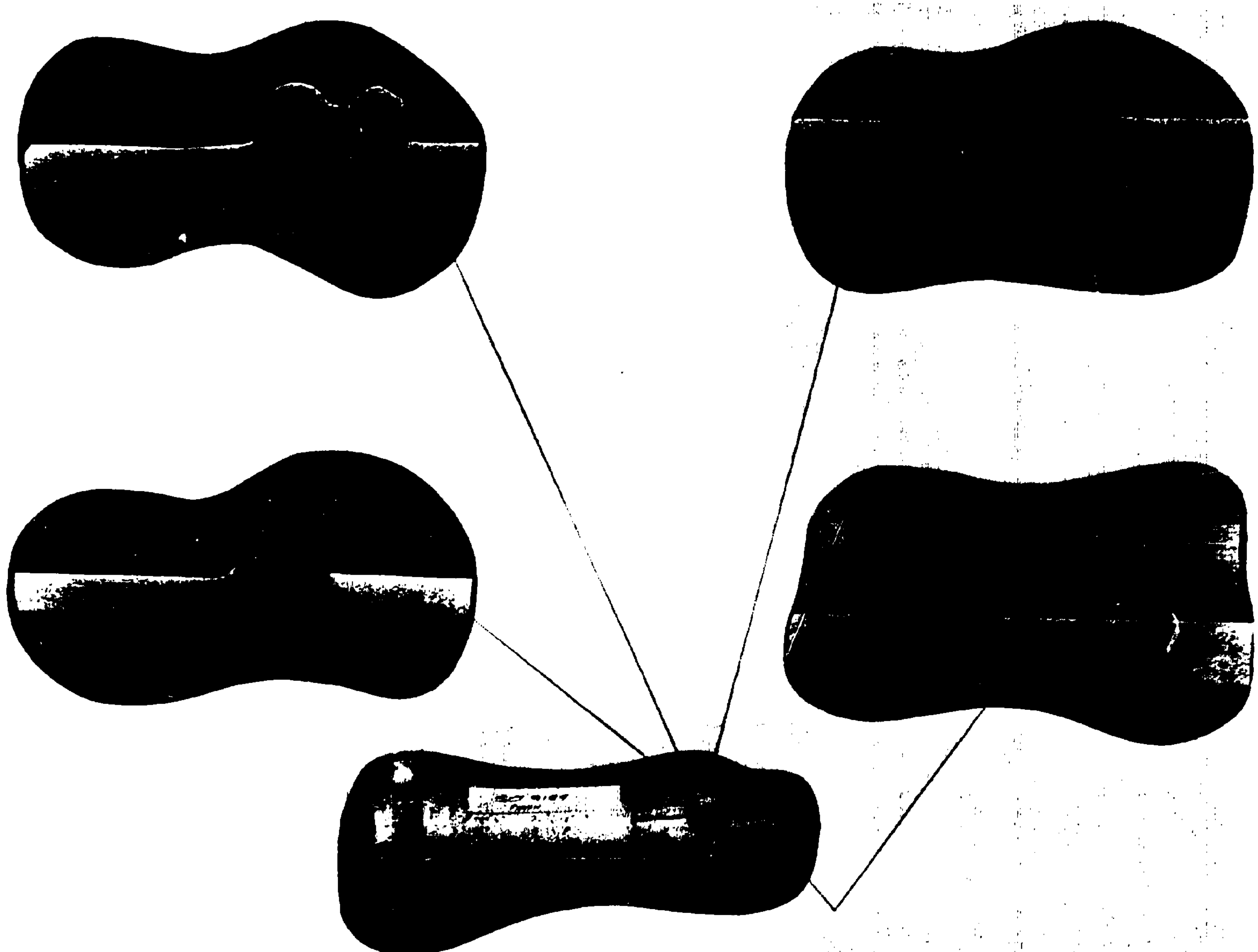


FIGURE 85 - S/N 1 -Macro Locations

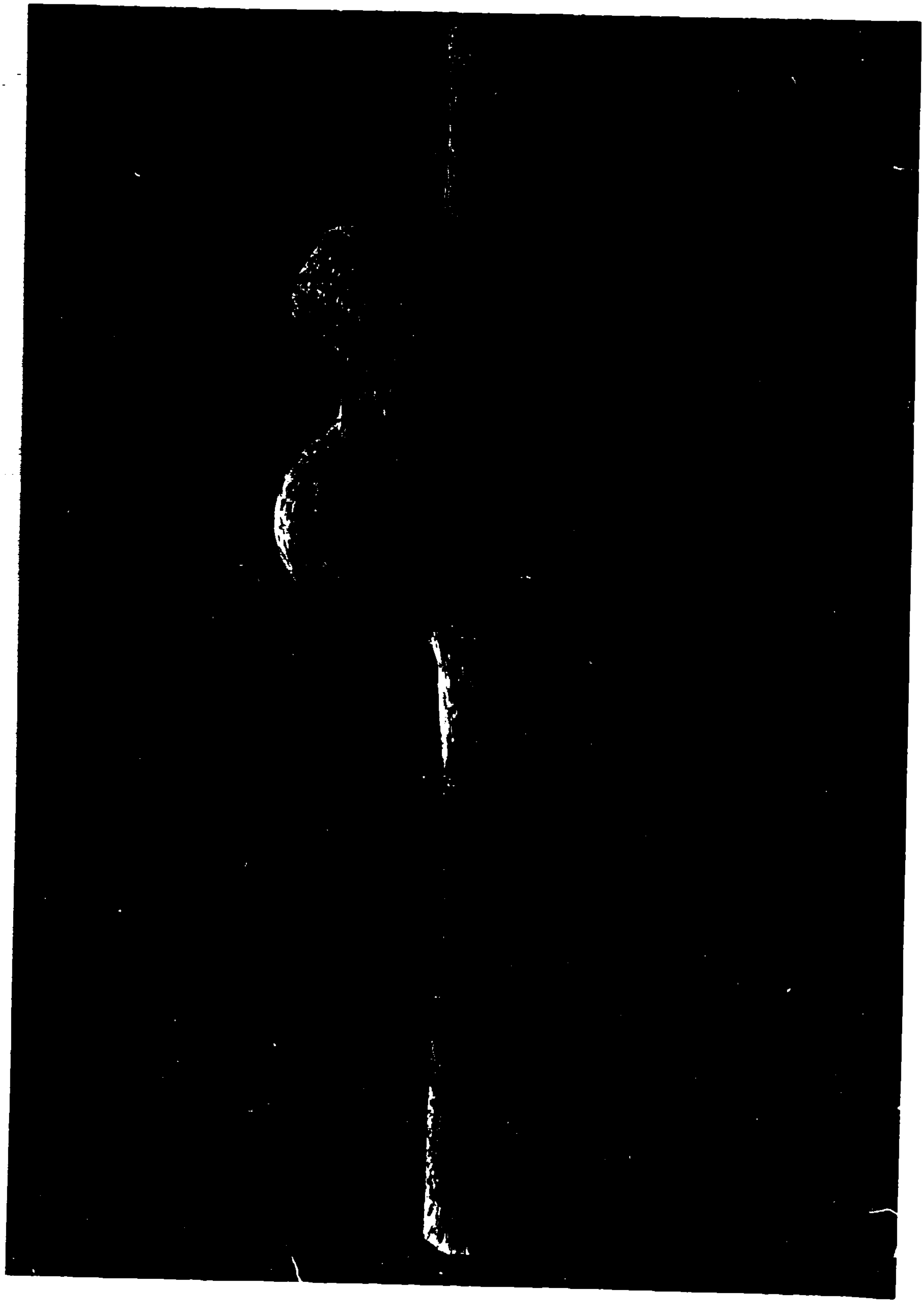


FIGURE 86 - Macro Location "A" - S/N 1

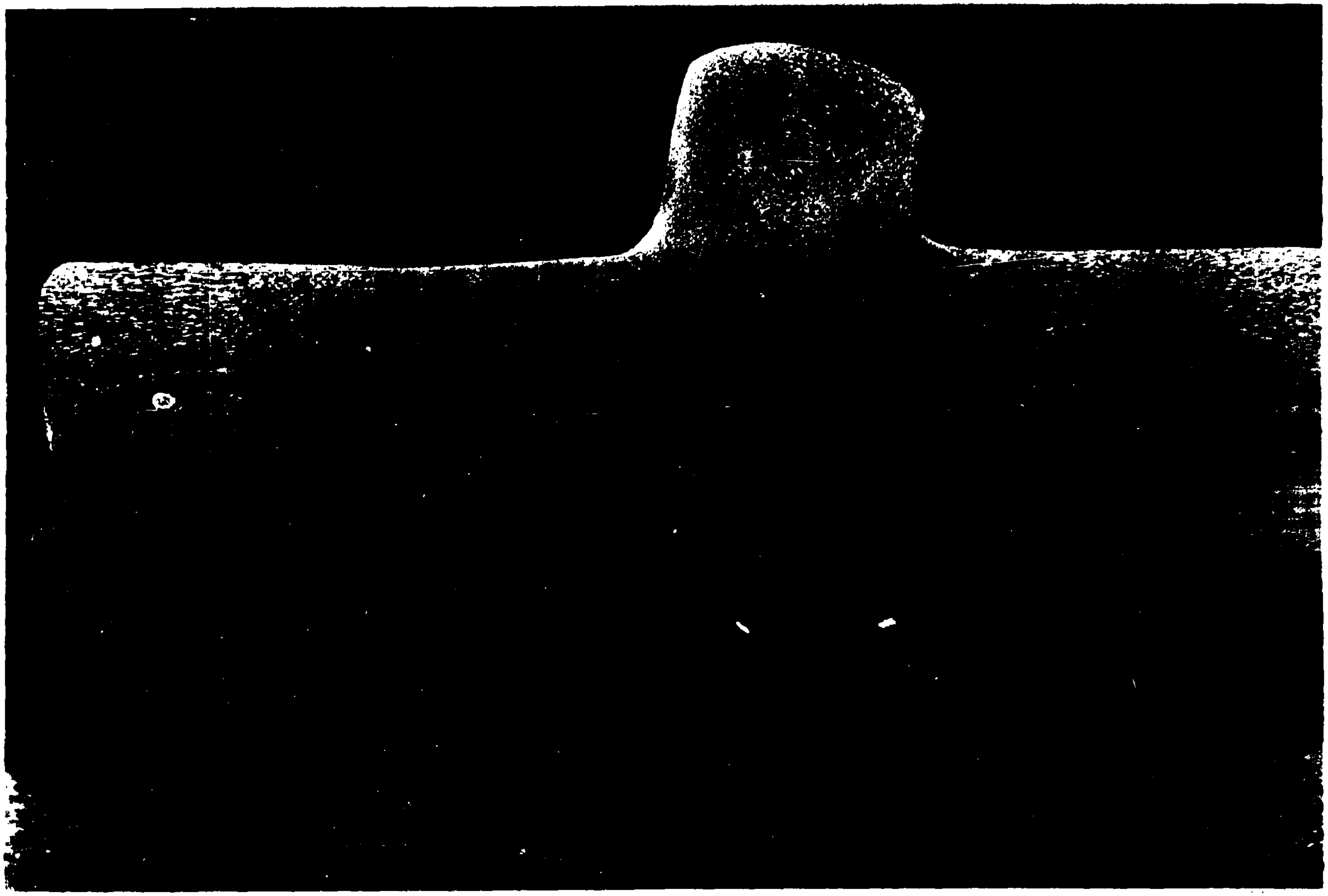


FIGURE 87 - Macro Location "B" - S/N 1

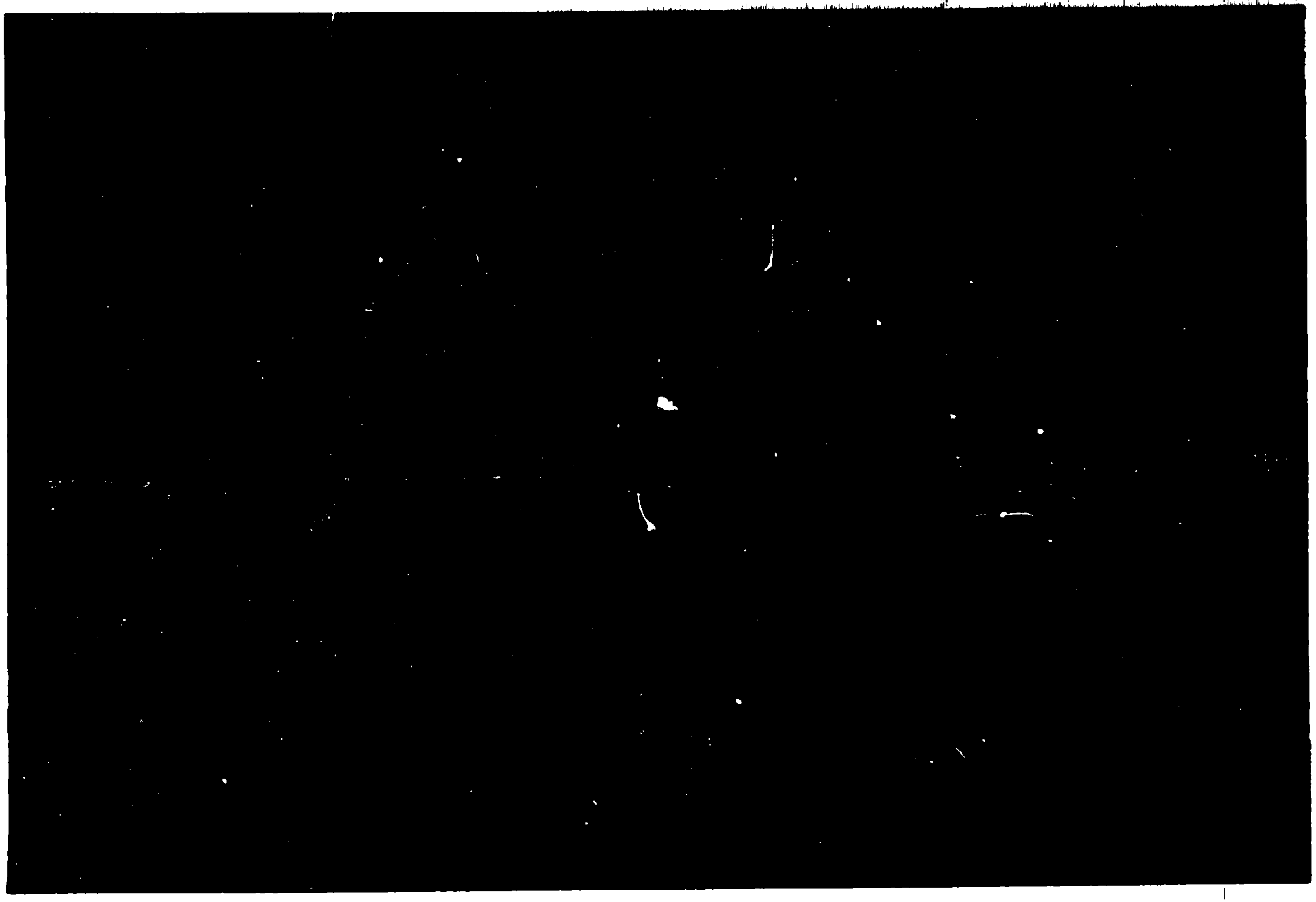


FIGURE 88 - Macro Location "C" - S/N 1

FIGURE 89 - Macro Location "D" - S/N 1

FIGURE 90 - Machined Plug

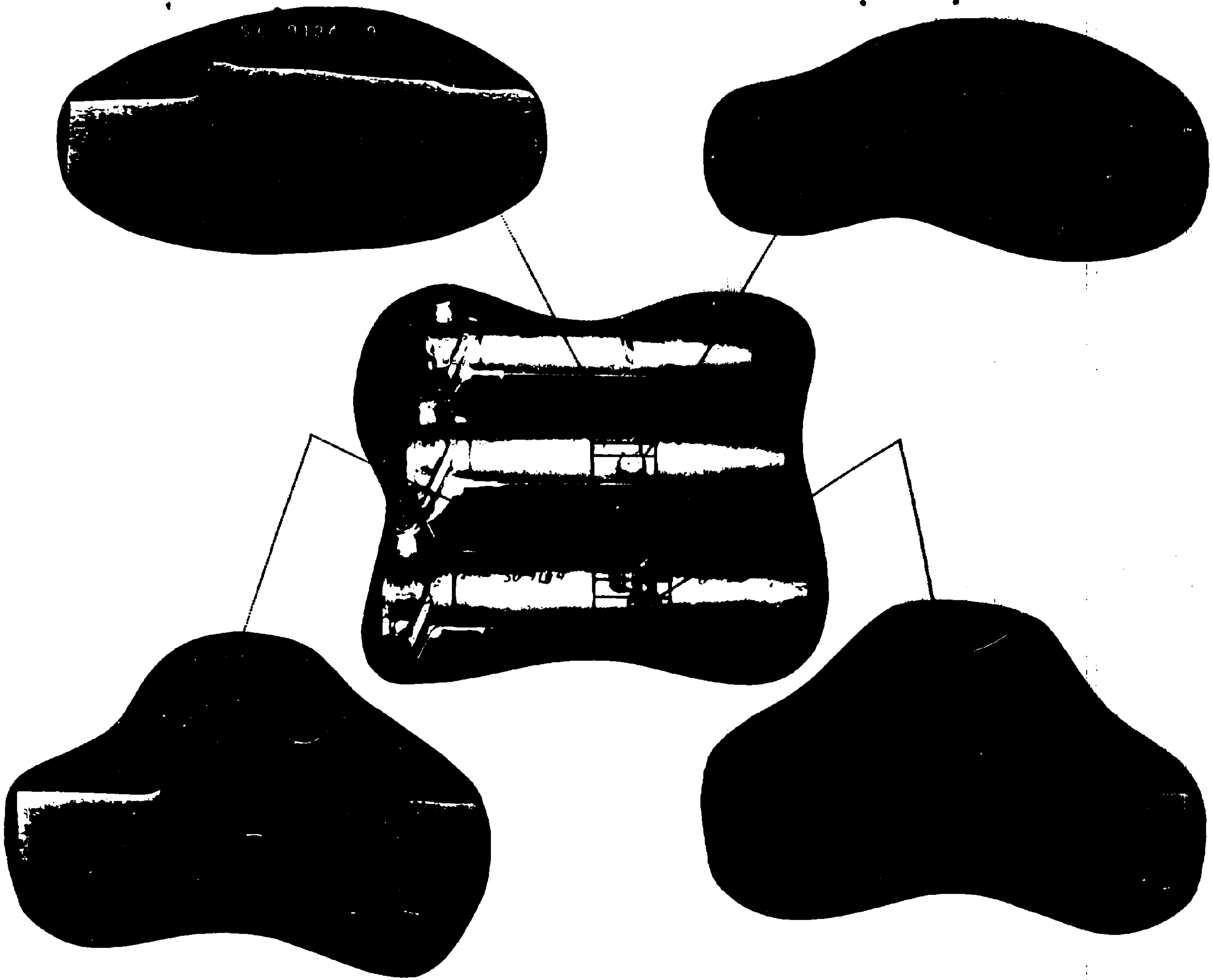


FIGURE 91 - Macro Locations Taken from S/N's 8 & 9

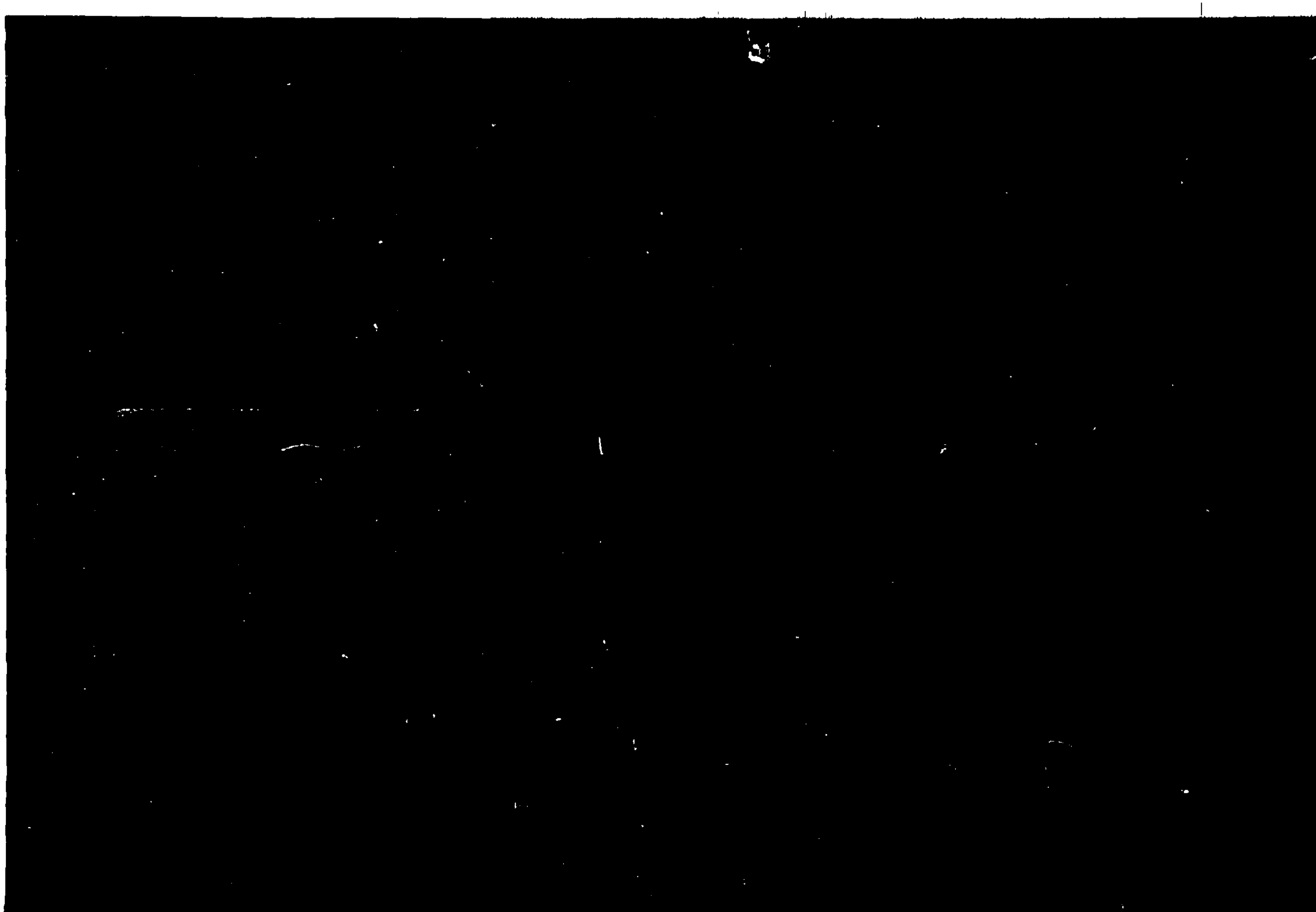


FIGURE 92 - Macro taken through heavy section of boss - S/N 8

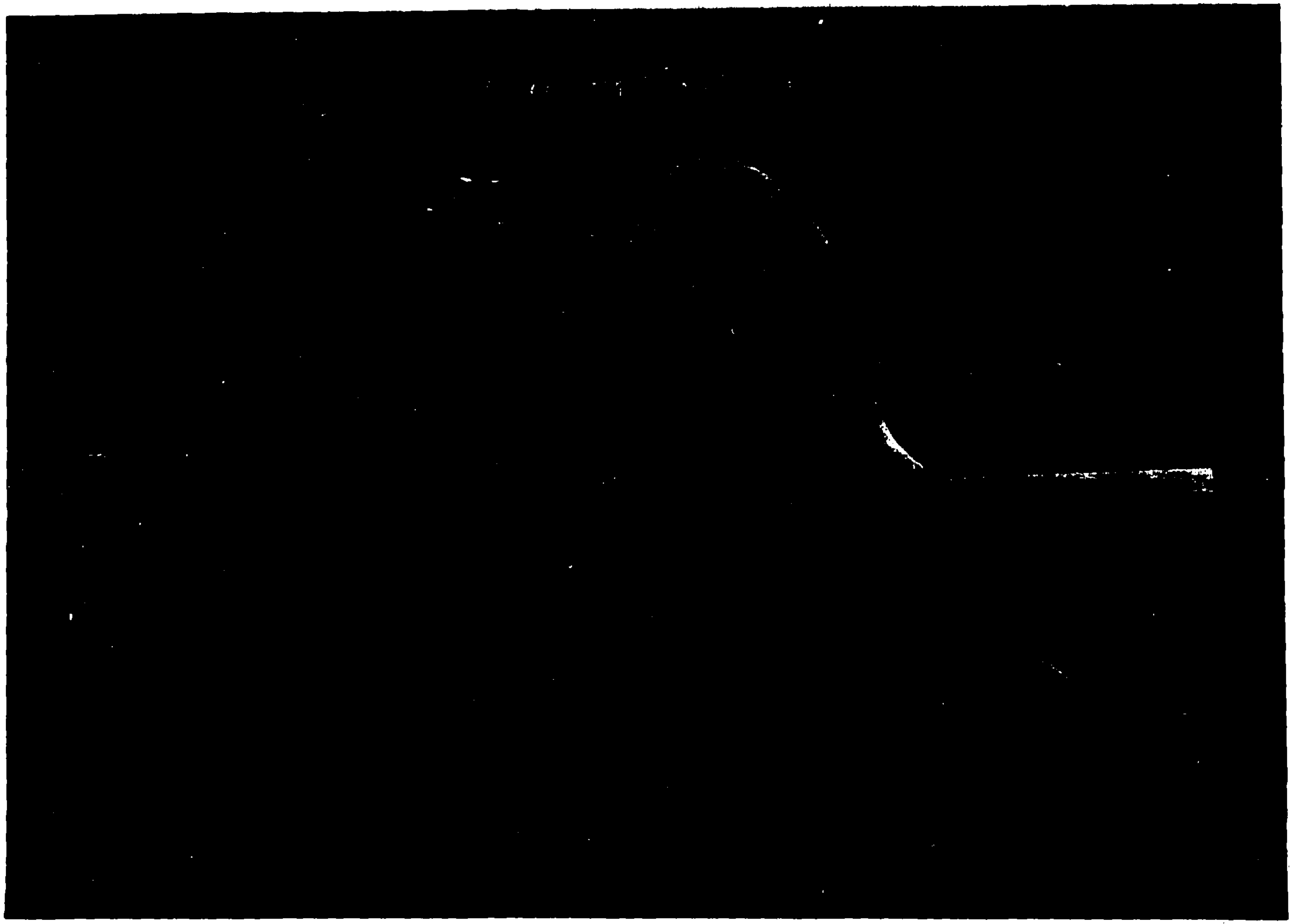


FIGURE 93 - Macro taken through narrow portion of boss - S/N 8

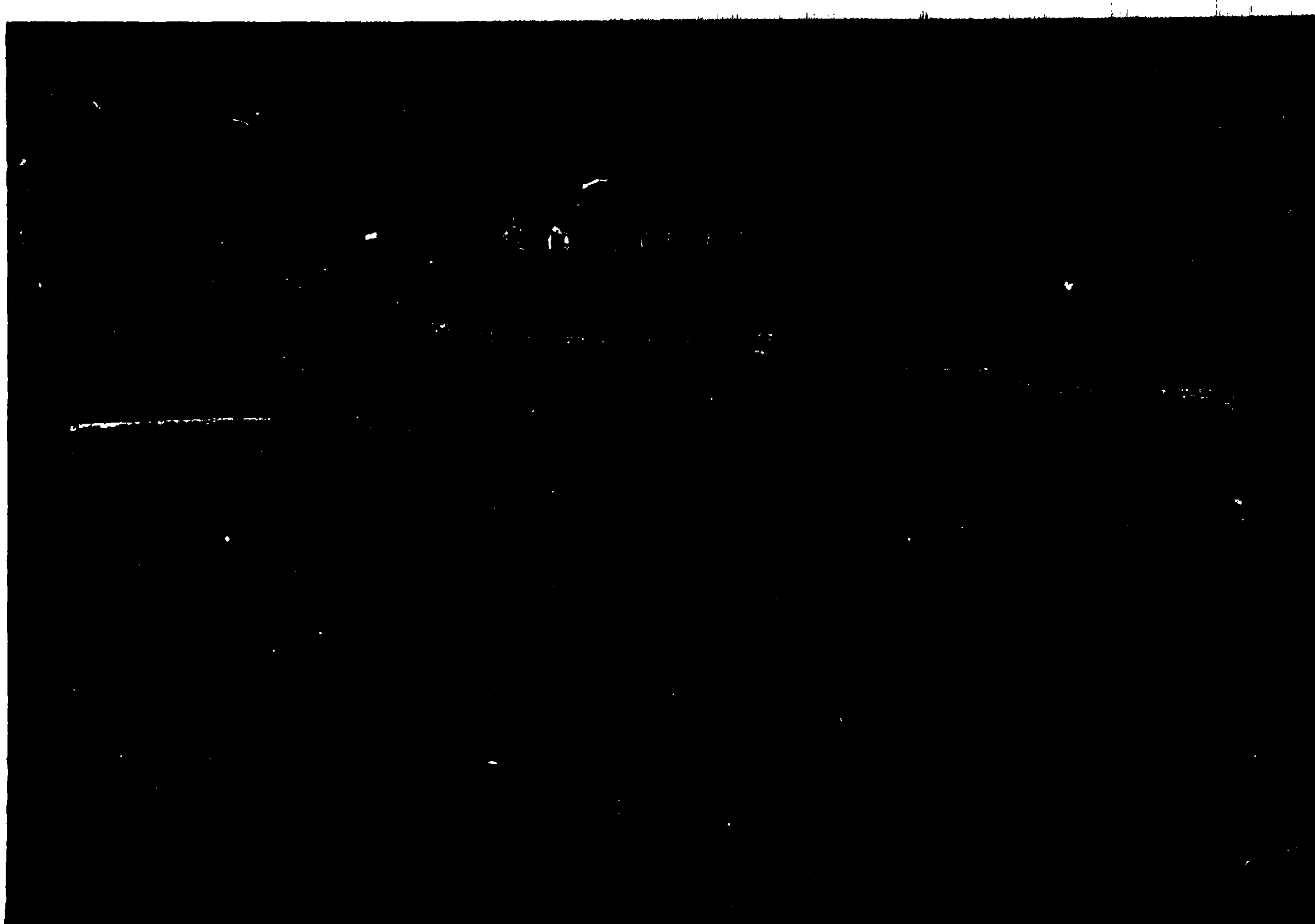


FIGURE 94 - Macro taken through heavy section of boss - S/N 9

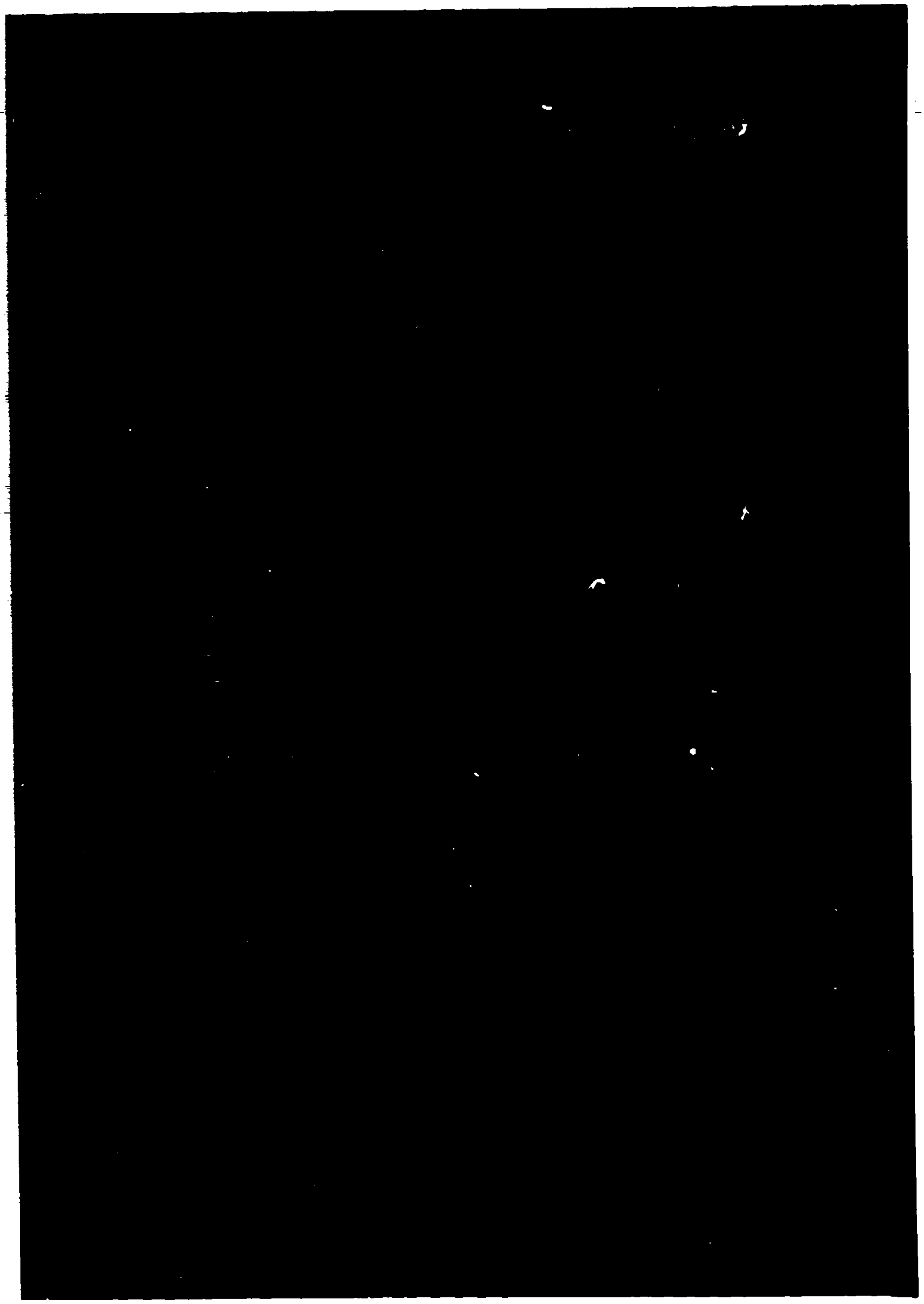


FIGURE 95 - Macro taken through narrow portion of boss - S/N 9

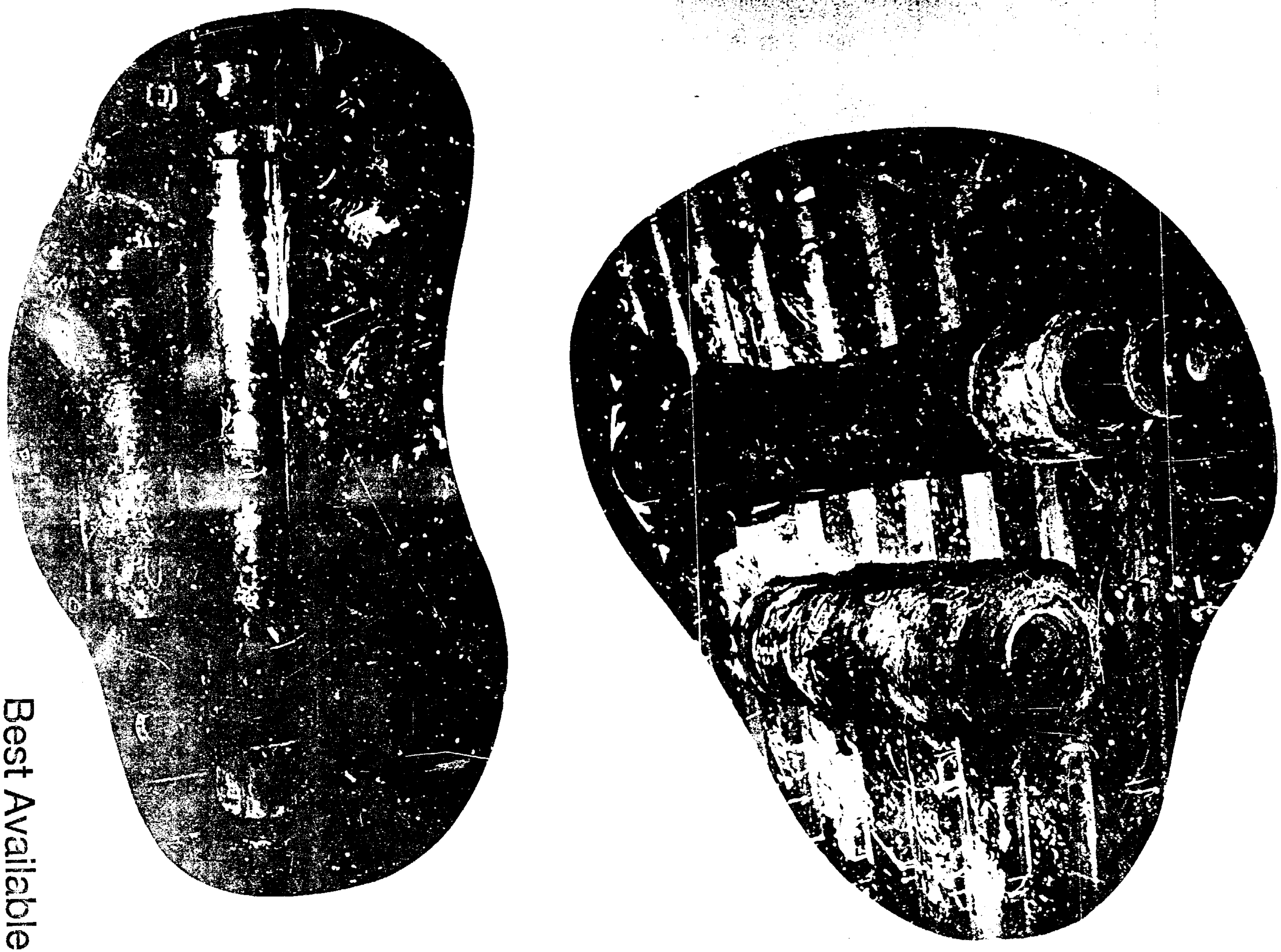


FIGURE 96 - Punch failure - S/N 4

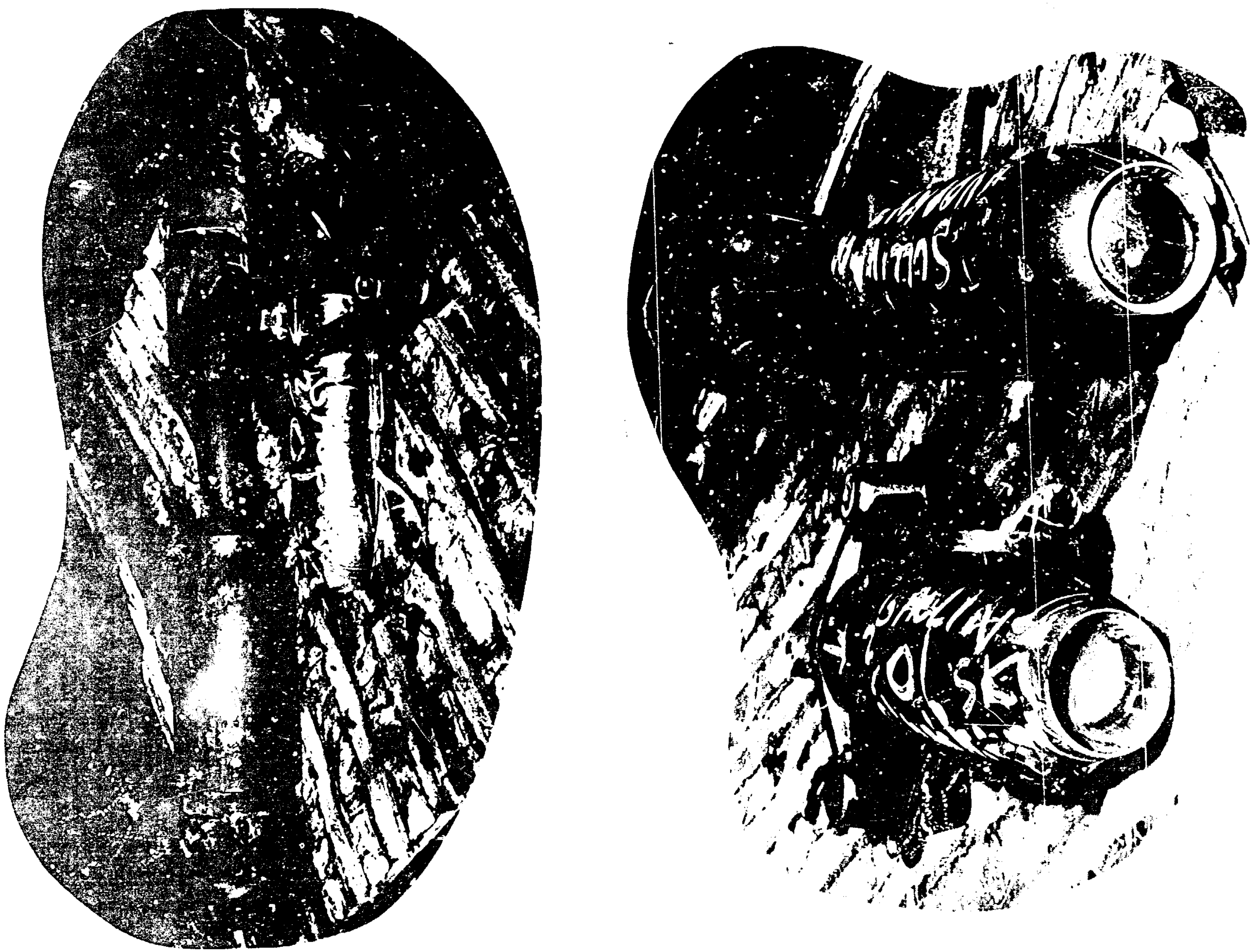


FIGURE 97 - Punch failure - S/N 10

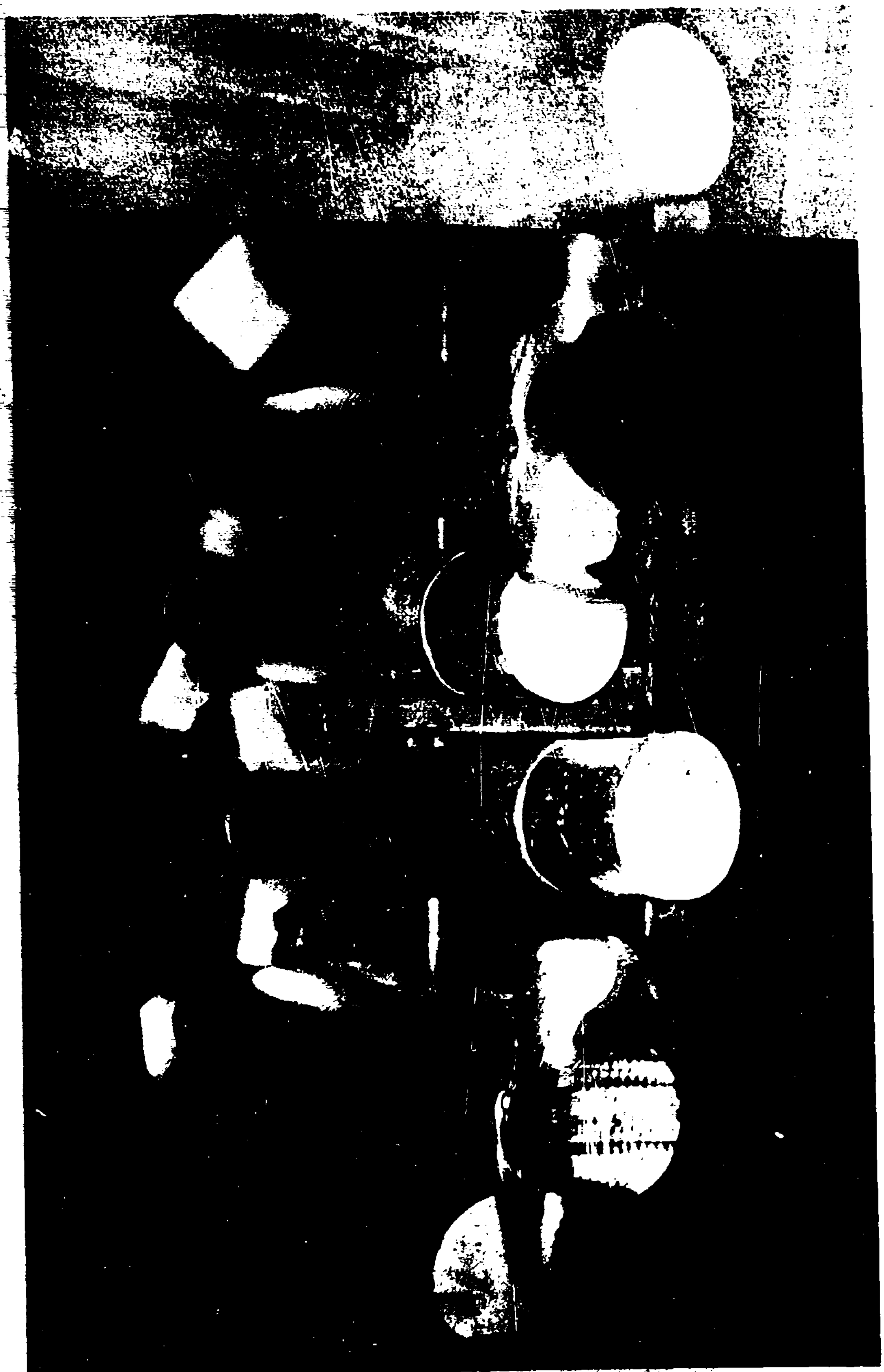
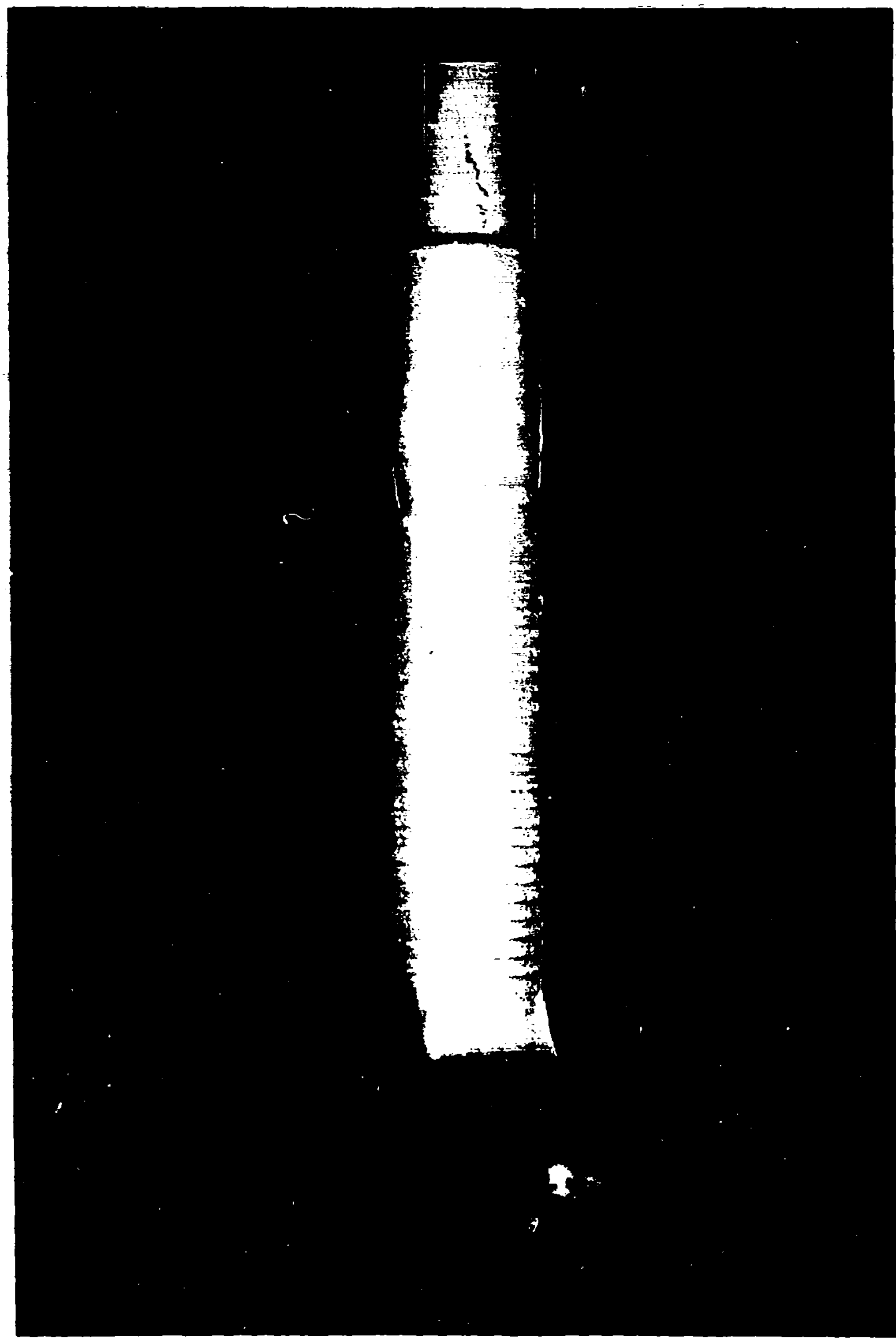


FIGURE 98 - No. 1 Upset - S/N's 5, 6, 7, 12 & 13

FIGURE 99 - S/N 5 - No. 1 Upset



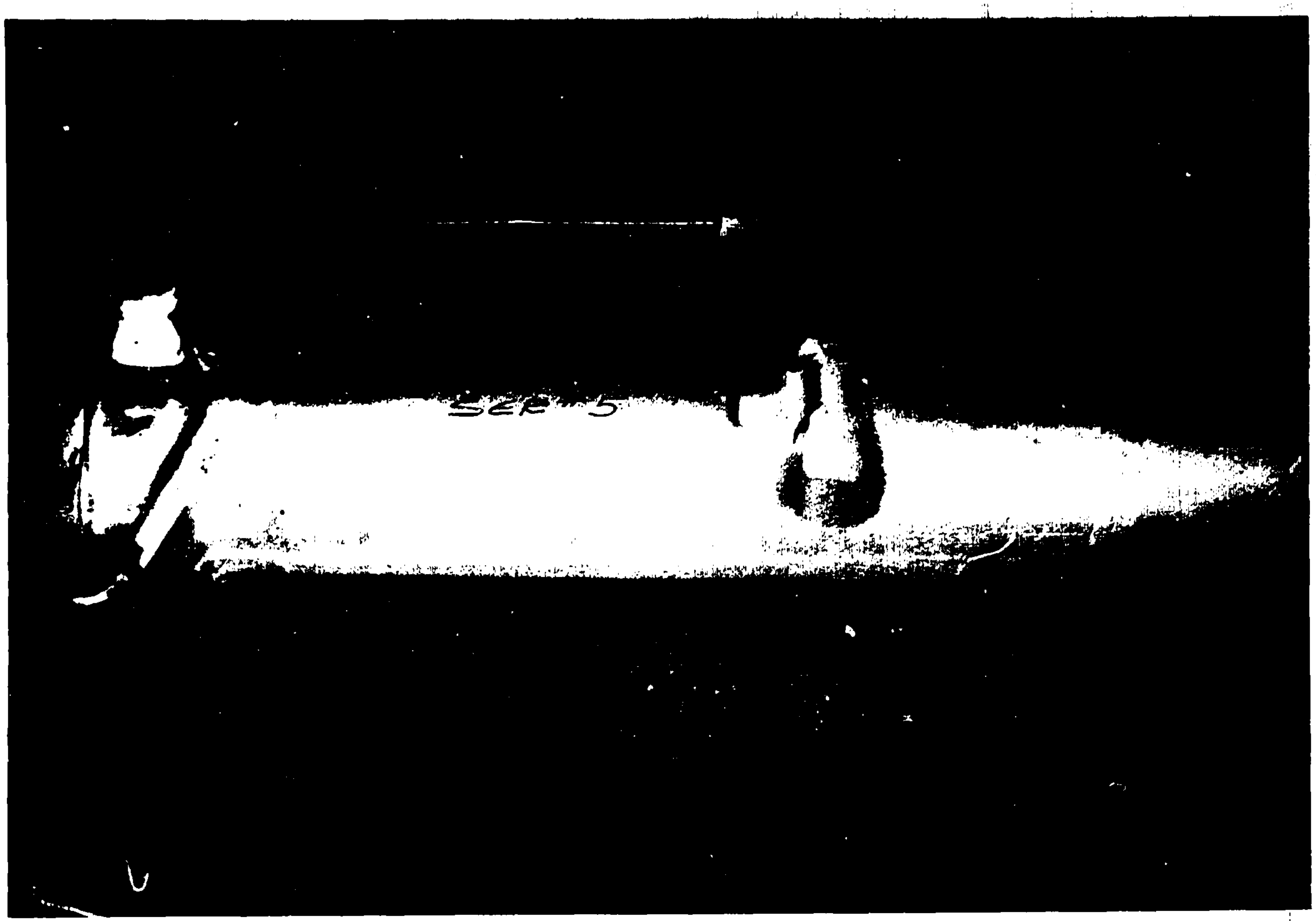


FIGURE 100 - S/N 5 - Back Extrusion & Upset

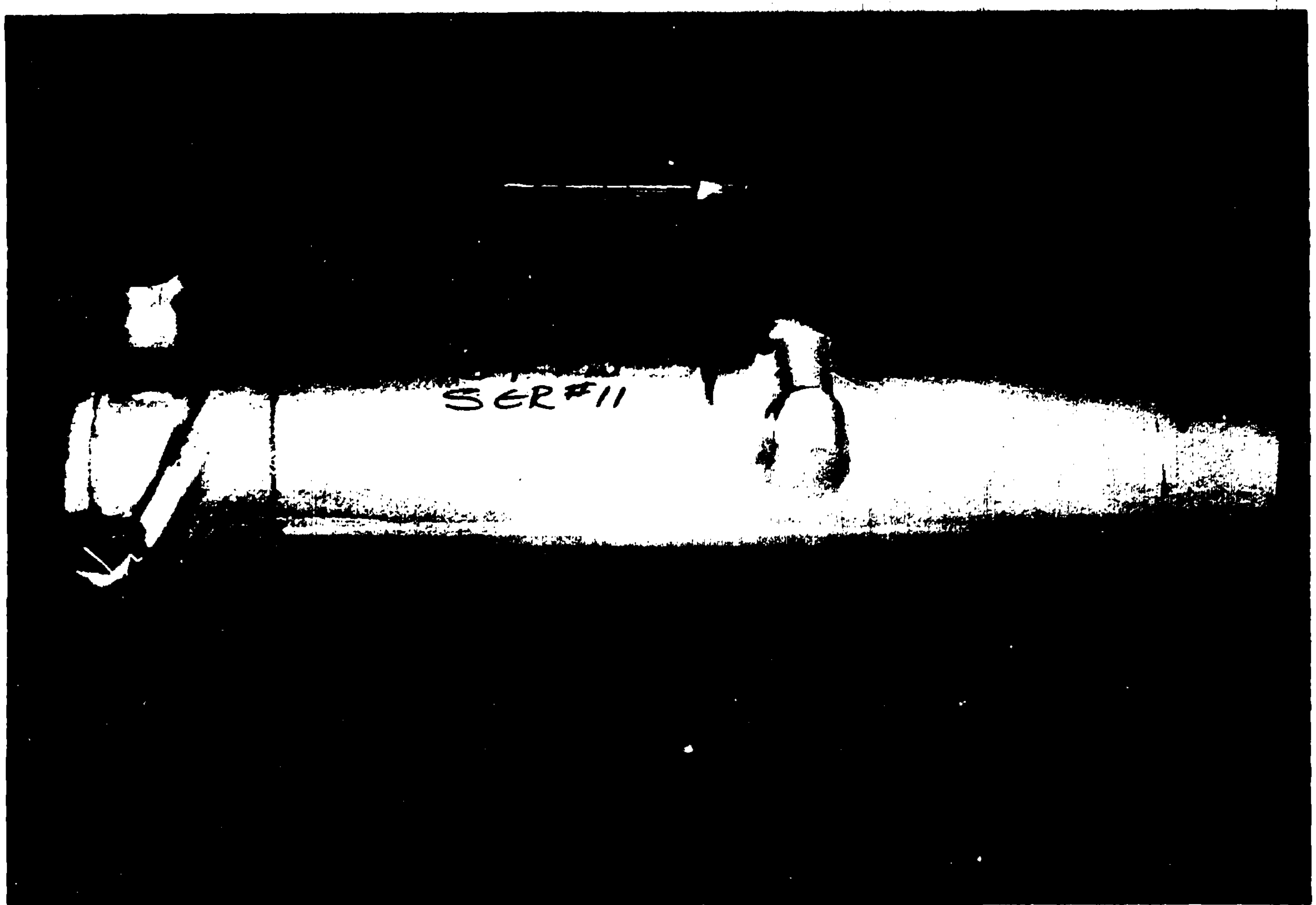


FIGURE 101 - S/N 11 - Back Extrusion & Upset

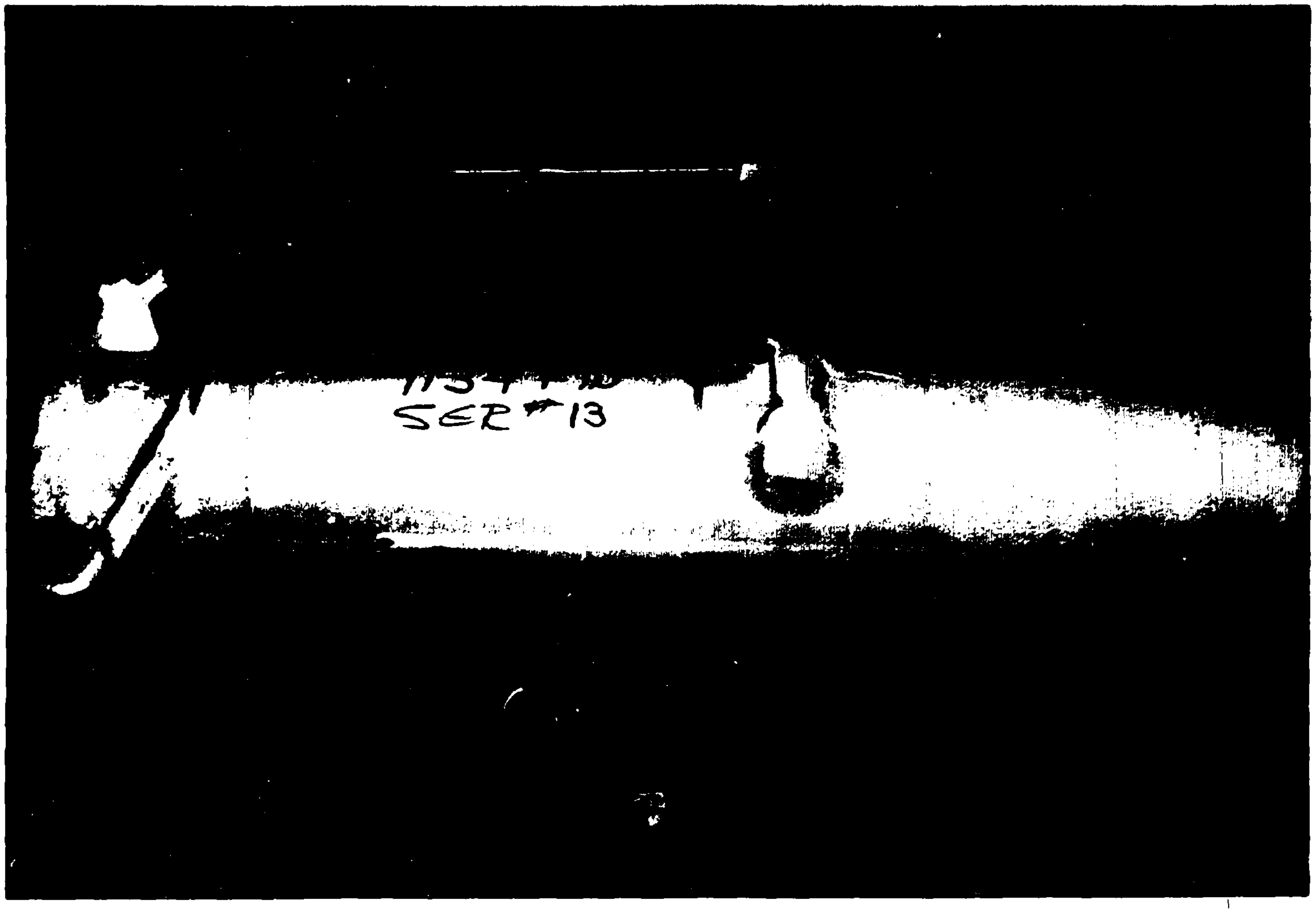


FIGURE 102 - S/N 13 - Back Extrusion & Upset

FIGURE 103 - S/N 14 - Back Extrusion & Upset

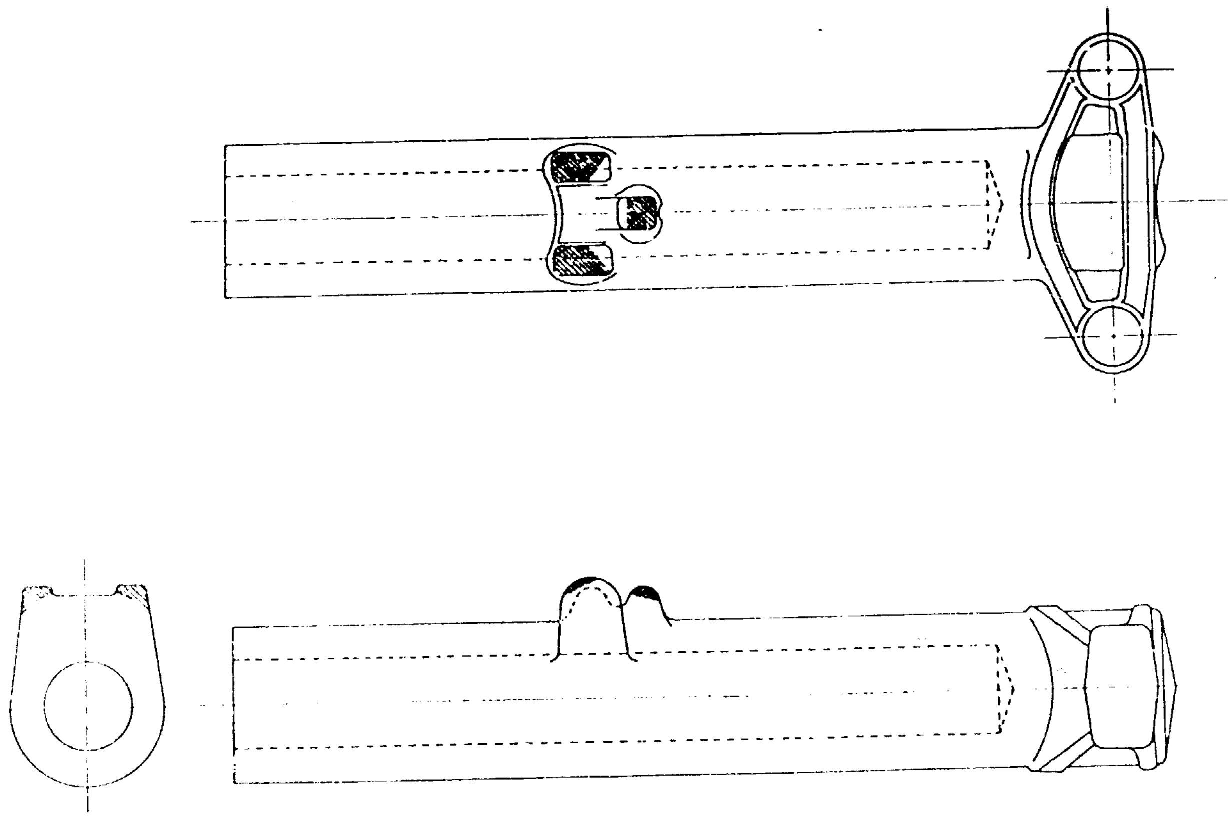


FIGURE 104 - Unfilled Condition - S/N 11

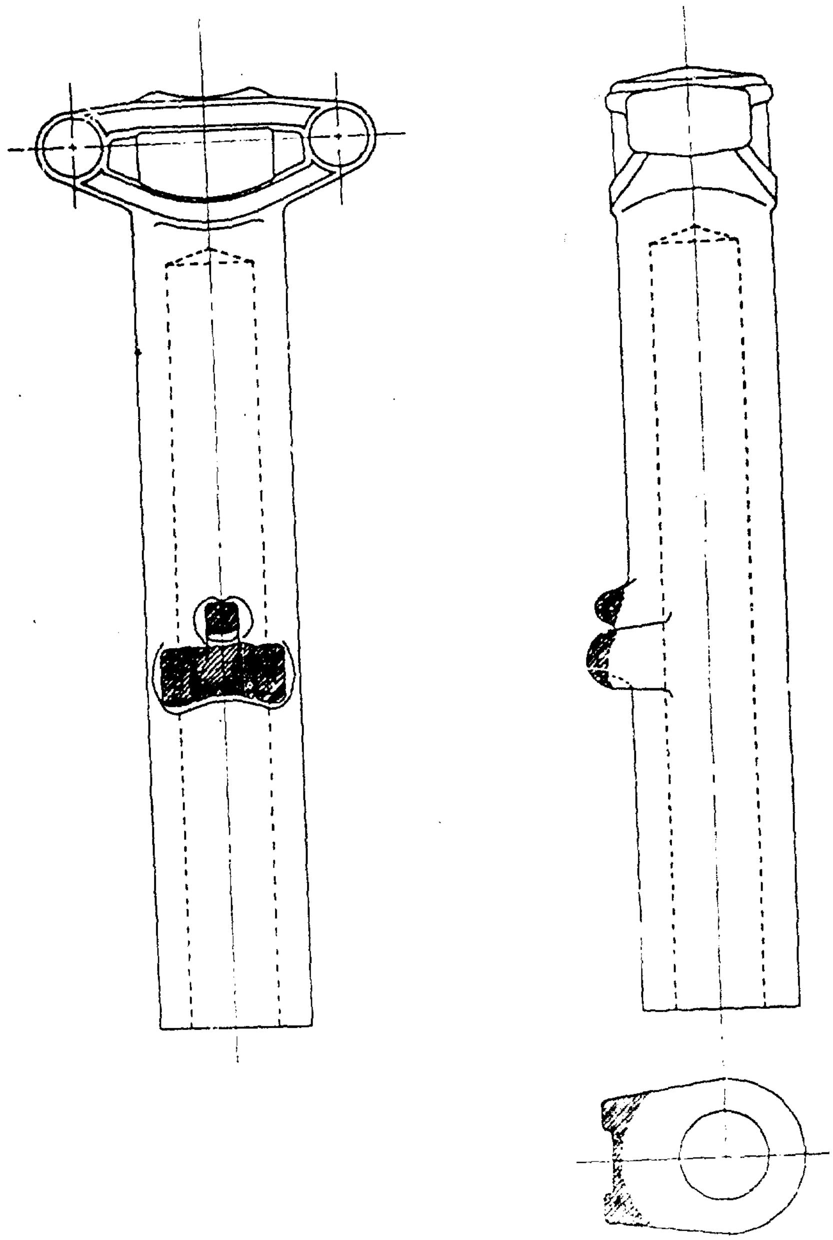


FIGURE 105 - Unfilled Condition - S/N 13

Best Available Copy

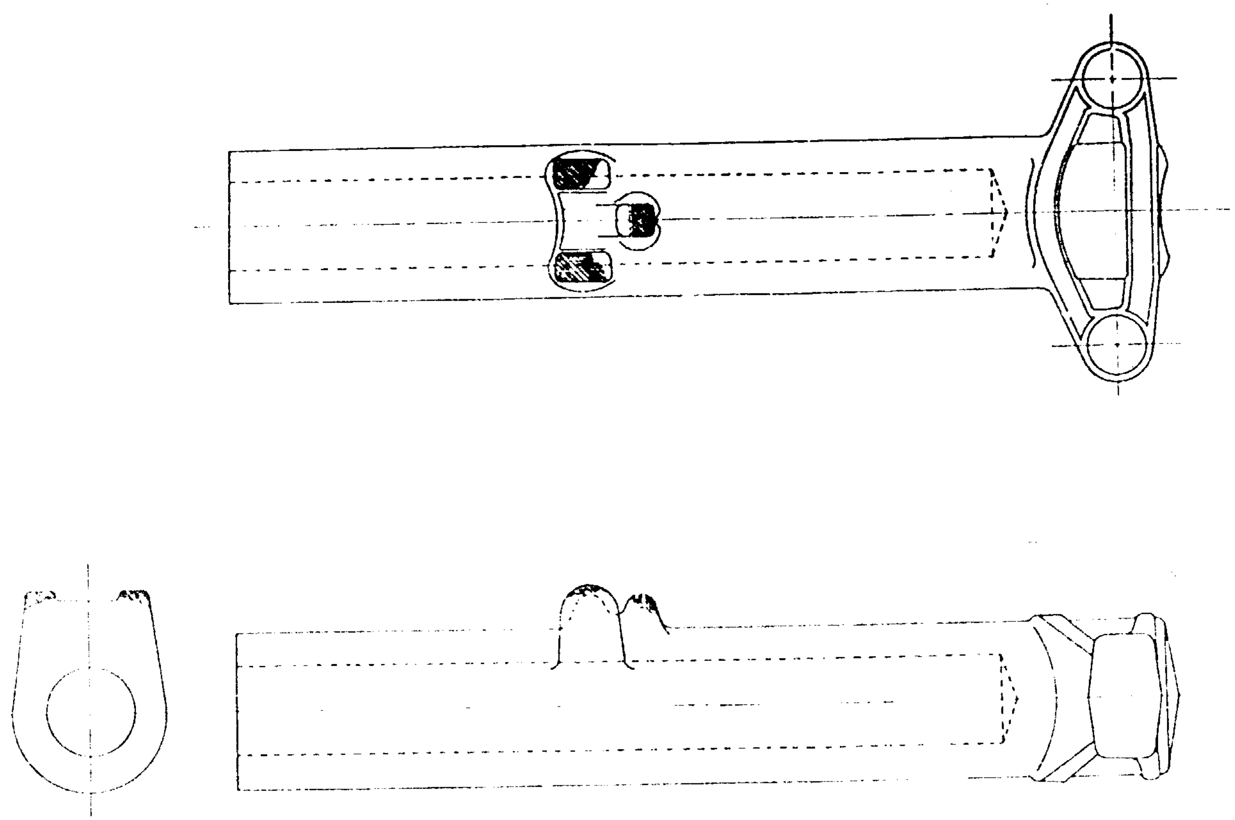
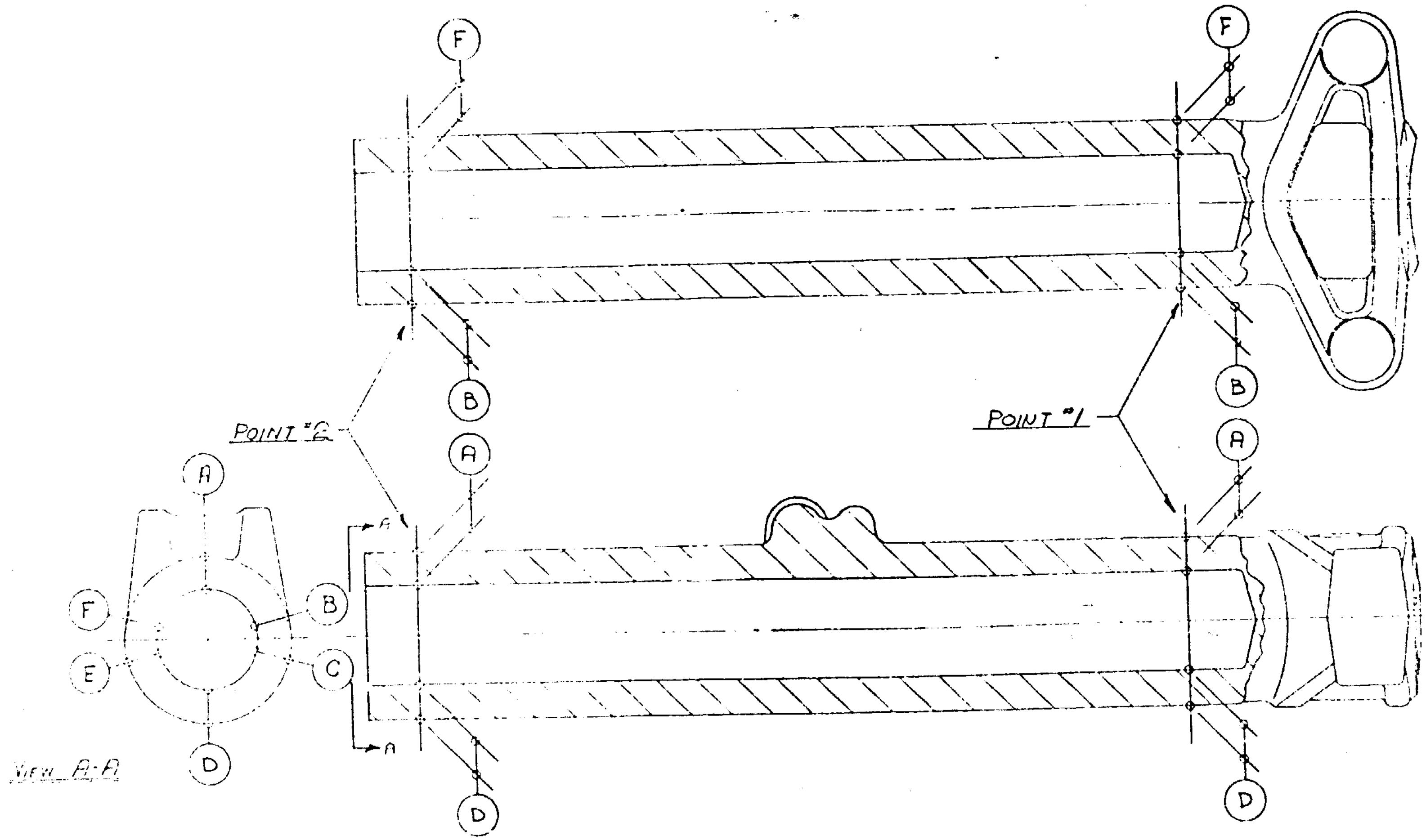
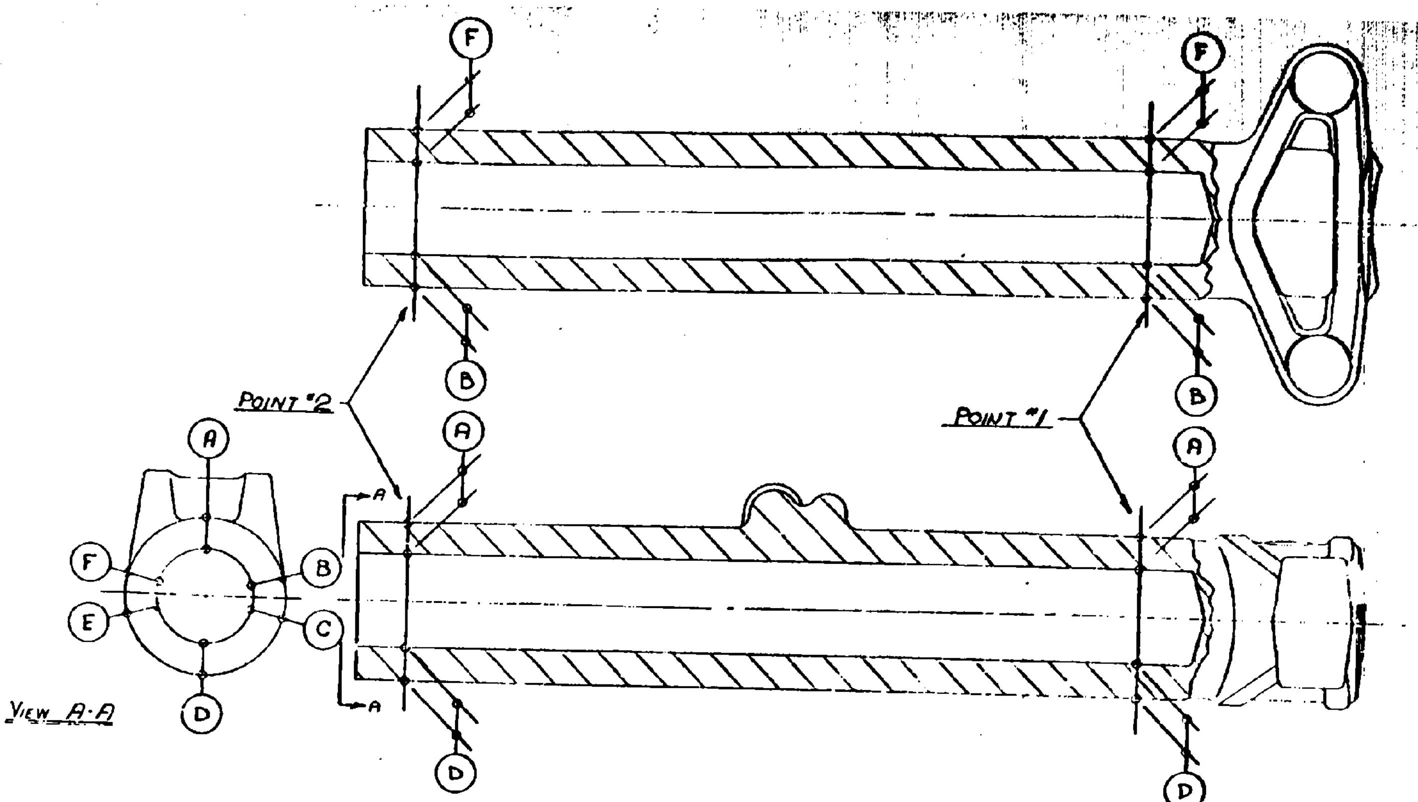


FIGURE 106 - Unfilled Condition - S/N 14



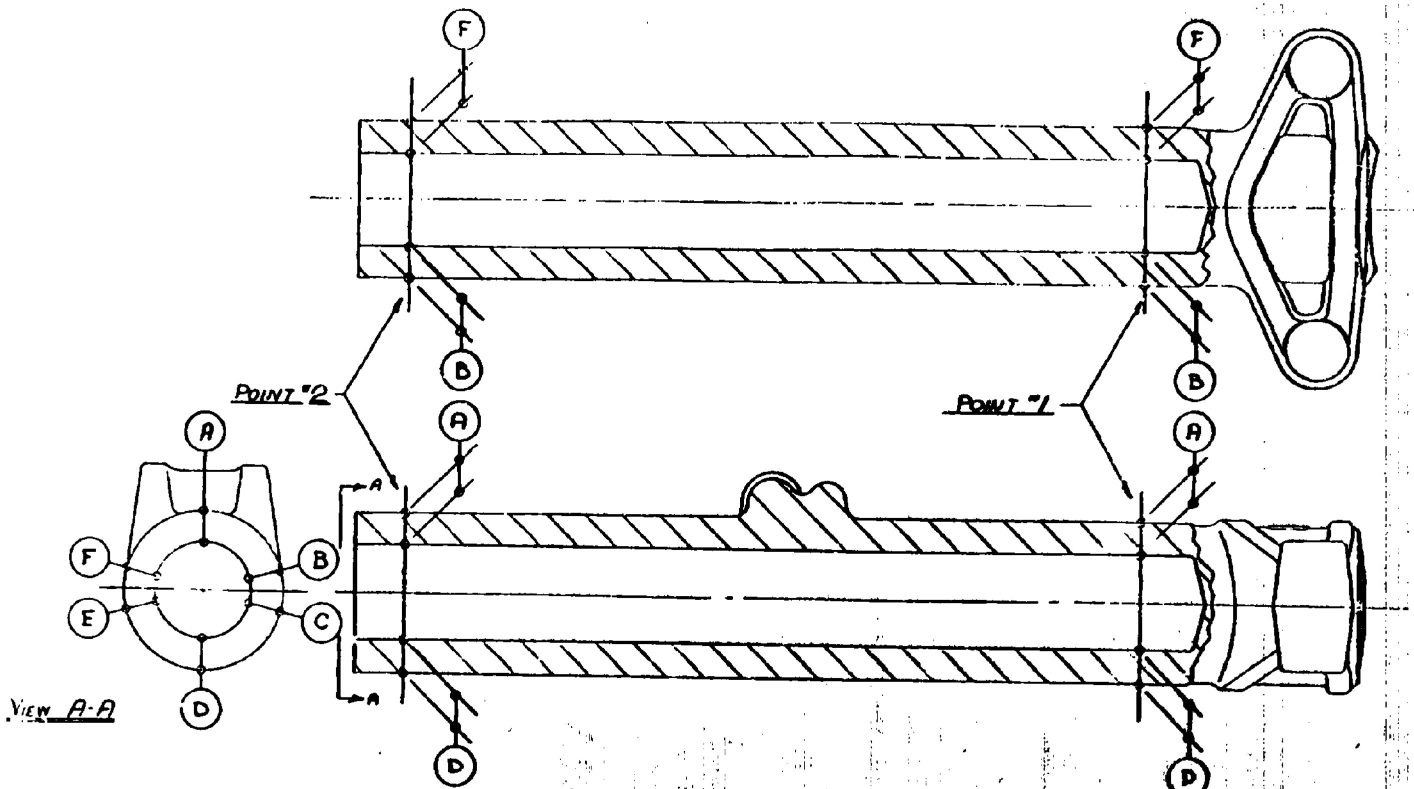
SERIAL No 2						
PT.	A	B	C	D	E	F
1	1.31	1.37	1.45	1.52	1.43	1.31
2	1.38	1.37	1.47	1.47	1.43	1.35

FIGURE 107 - Concentricity Layout - S/N 2



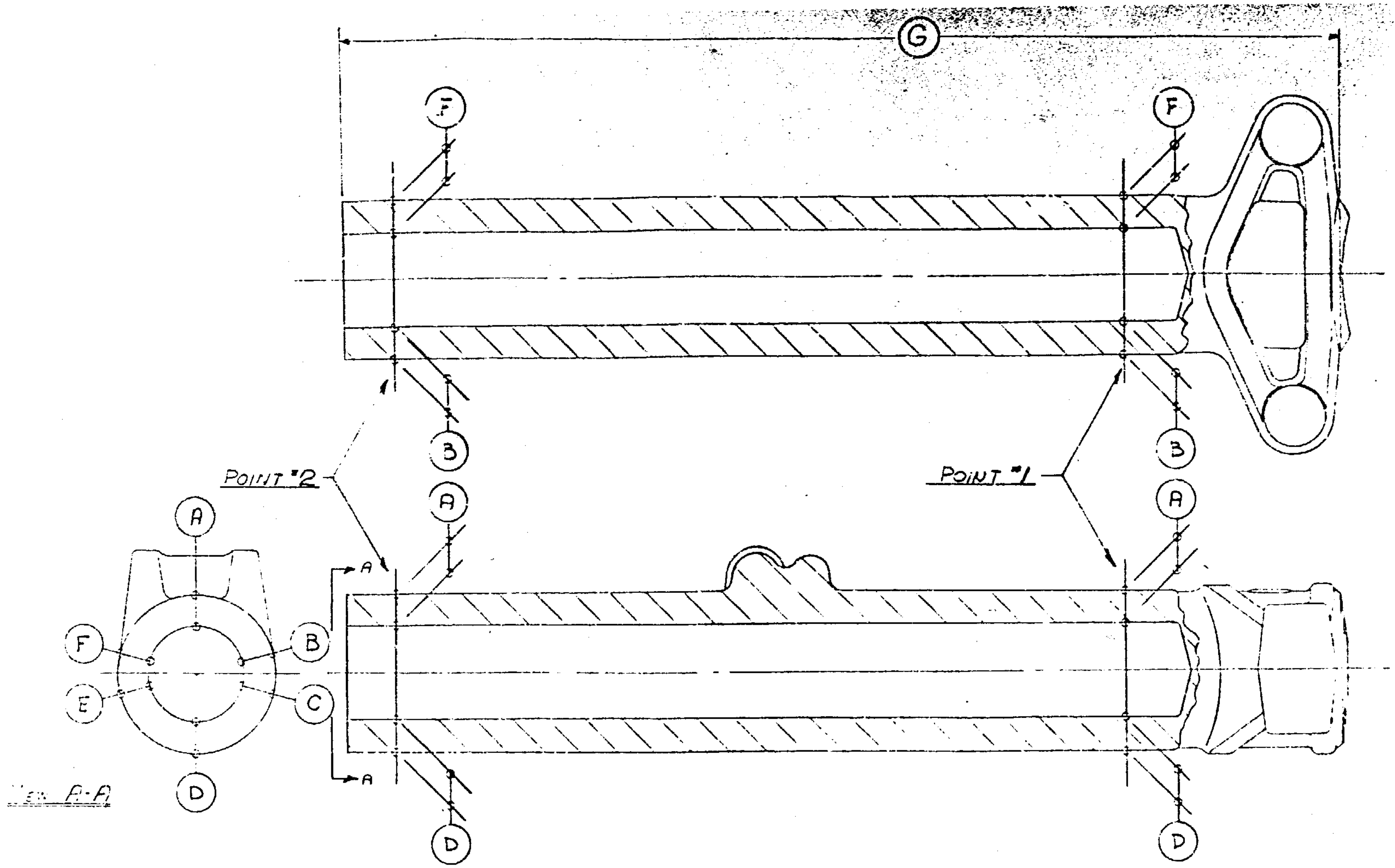
SERIAL No 8						
PT.	A	B	C	D	E	F
1	1.10	133	166	1.74	1.54	112
2	1.33	1.35	1.47	1.34	1.43	1.33

FIGURE 108 - Concentricity Layout - S/N 8



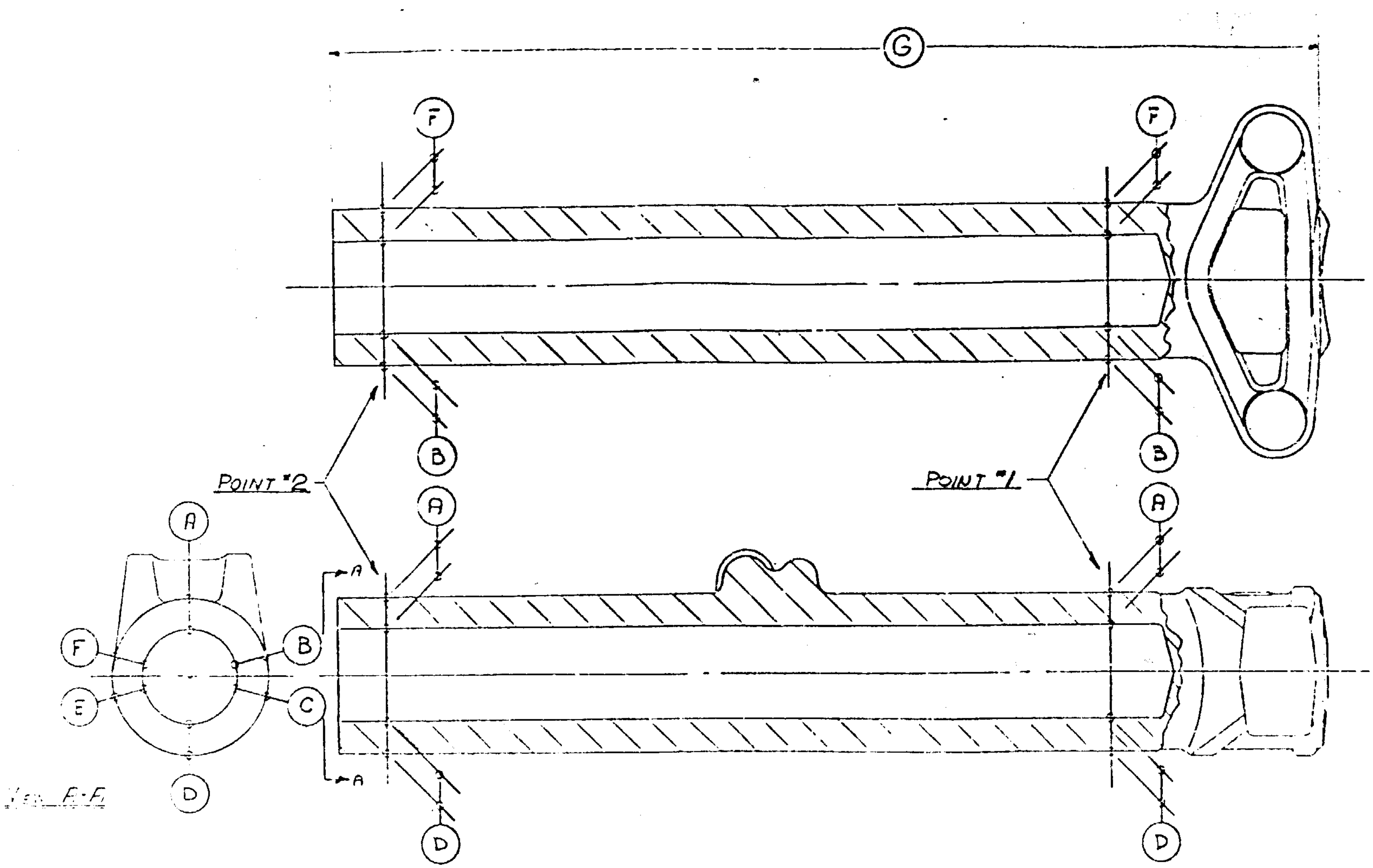
SERIAL NO 9						
PT.	A	B	C	D	E	F
1	[illegible]	[illegible]	1.53	1.37	[illegible]	[illegible]
2	[illegible]	1.37	1.44	[illegible]	[illegible]	[illegible]

FIGURE 109 - Concentricity Layout - S/N 9



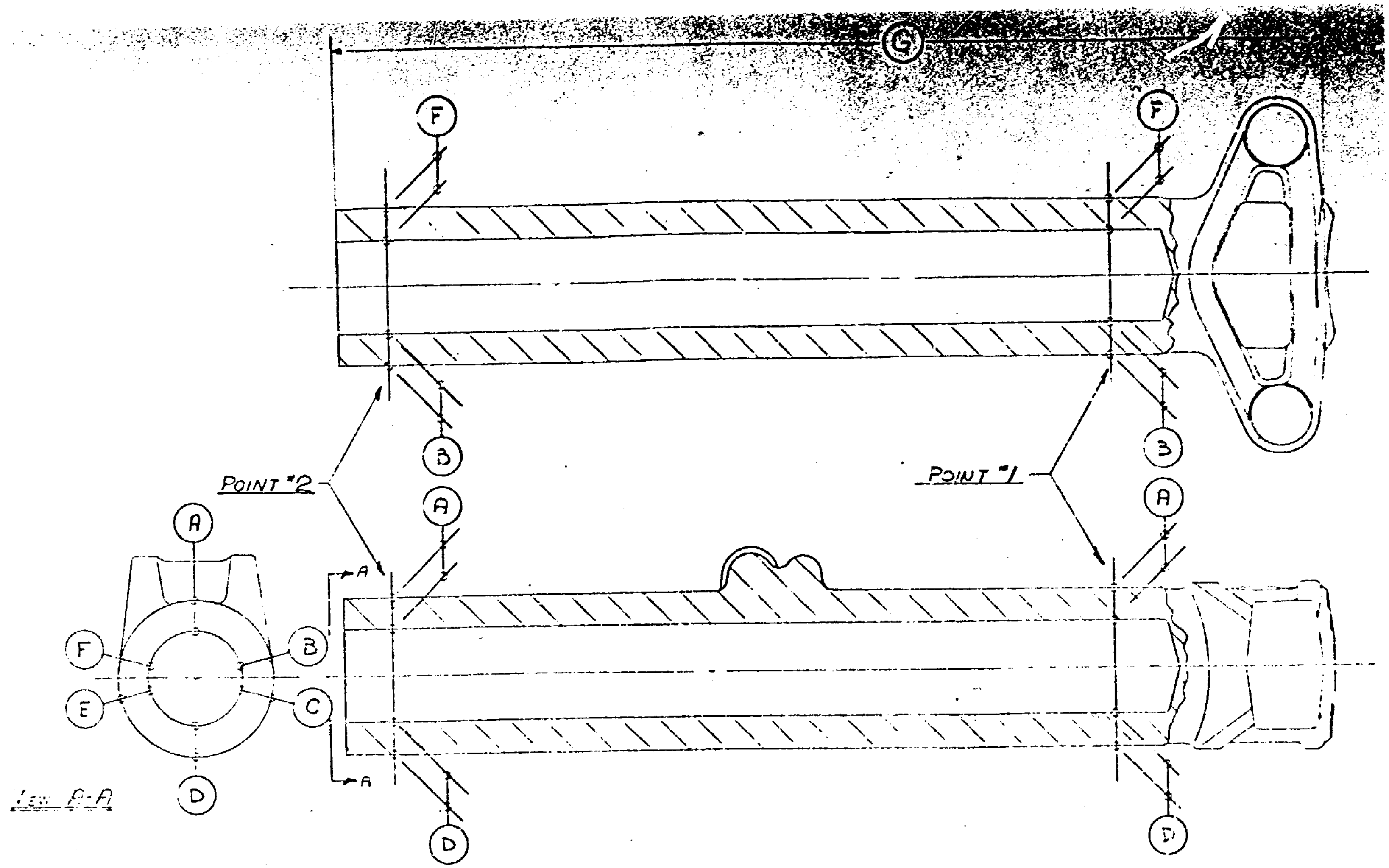
Serial No 11							
PT.	A	B	C	D	E	F	G
1	.127	.135	.147	.152	.138	.129	4.210
2	.136	.134	.133	.136	.129	.131	

FIGURE 110 - Concentricity Layout - S/N 11



SERIAL No 13							
PT.	A	B	C	D	E	F	G
1	.16	139	162	165	138	1.13	4210
2	137	1.33	1.34	137	134	134	

FIGURE 111 - Concentricity Layout - S/N 13



SERIAL No 14							
PT.	A	B	C	D	E	F	G
1	1.23	1.43	1.58	1.60	1.28	1.2	41.75
2	1.37	1.34	1.31	1.36	1.33	1.33	

FIGURE 112 - Concentricity Layout - S/N 14

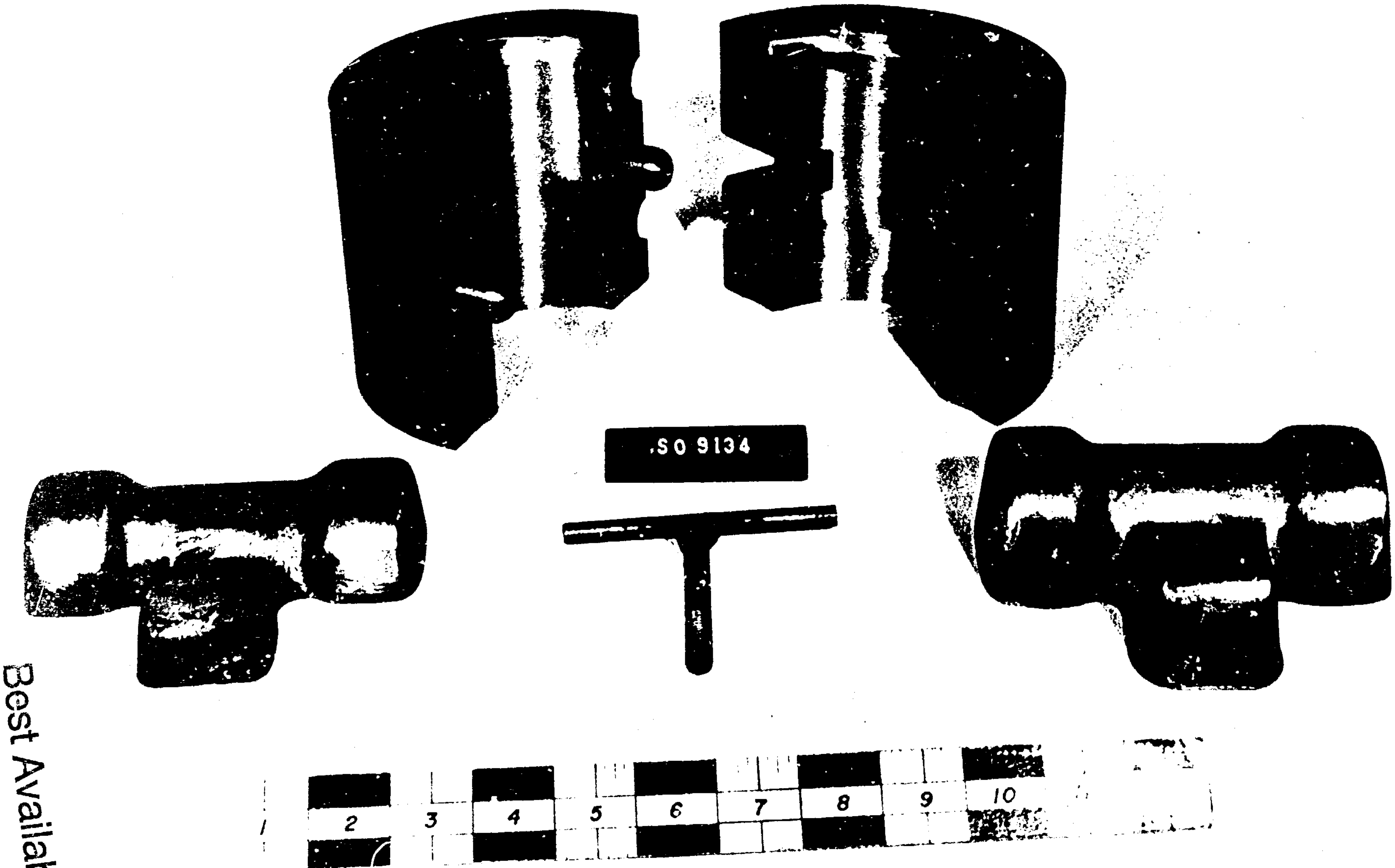


FIGURE 113 - Split Guide Ring & Inserts

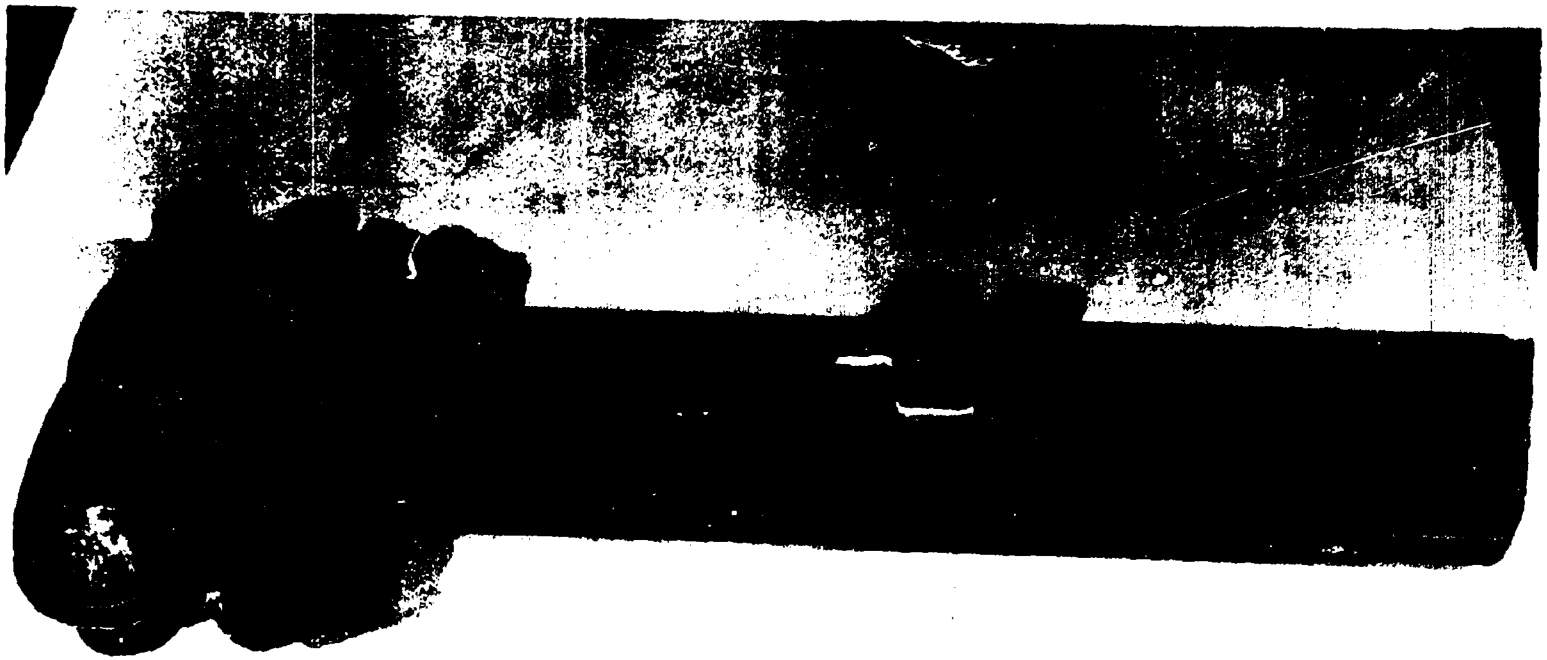


FIGURE 114 - First Boss Upset

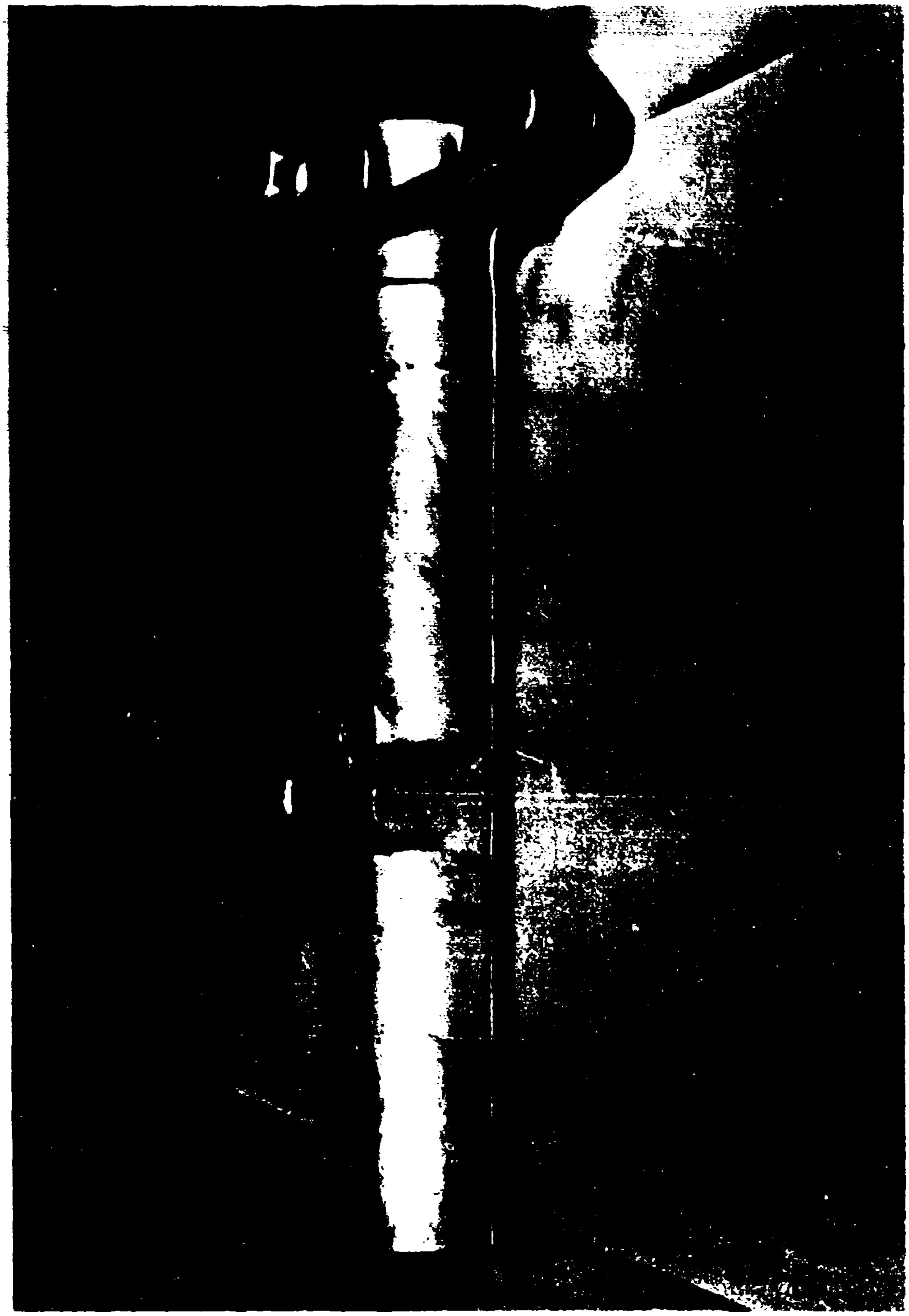


FIGURE 115 - Finished Piece

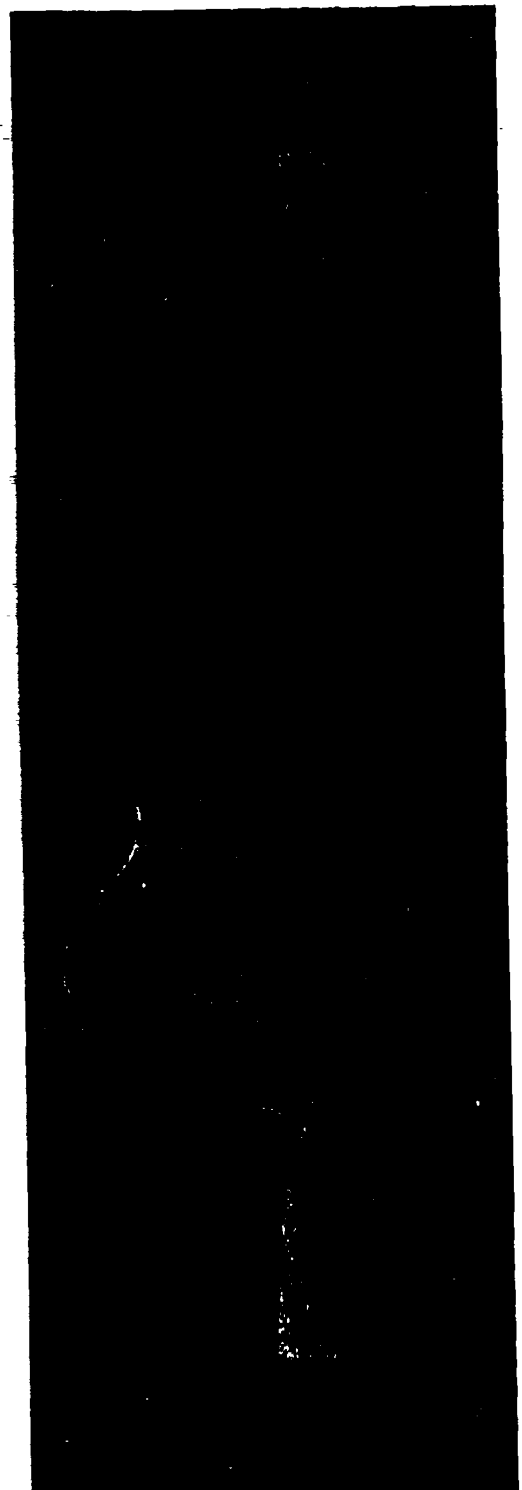


FIGURE 116 - Section through the central boss

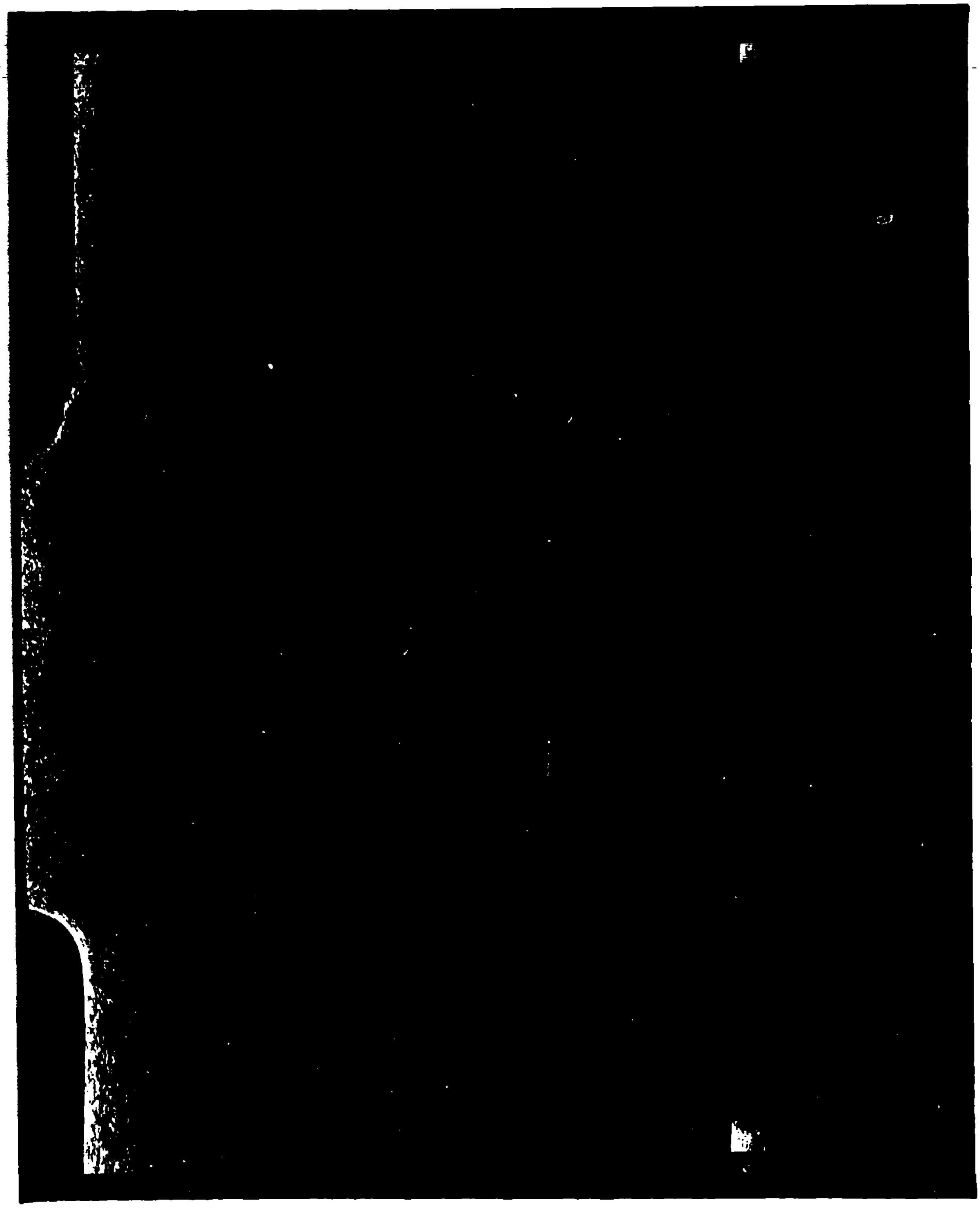


FIGURE 117 - Lap in the central boss after first boss upset

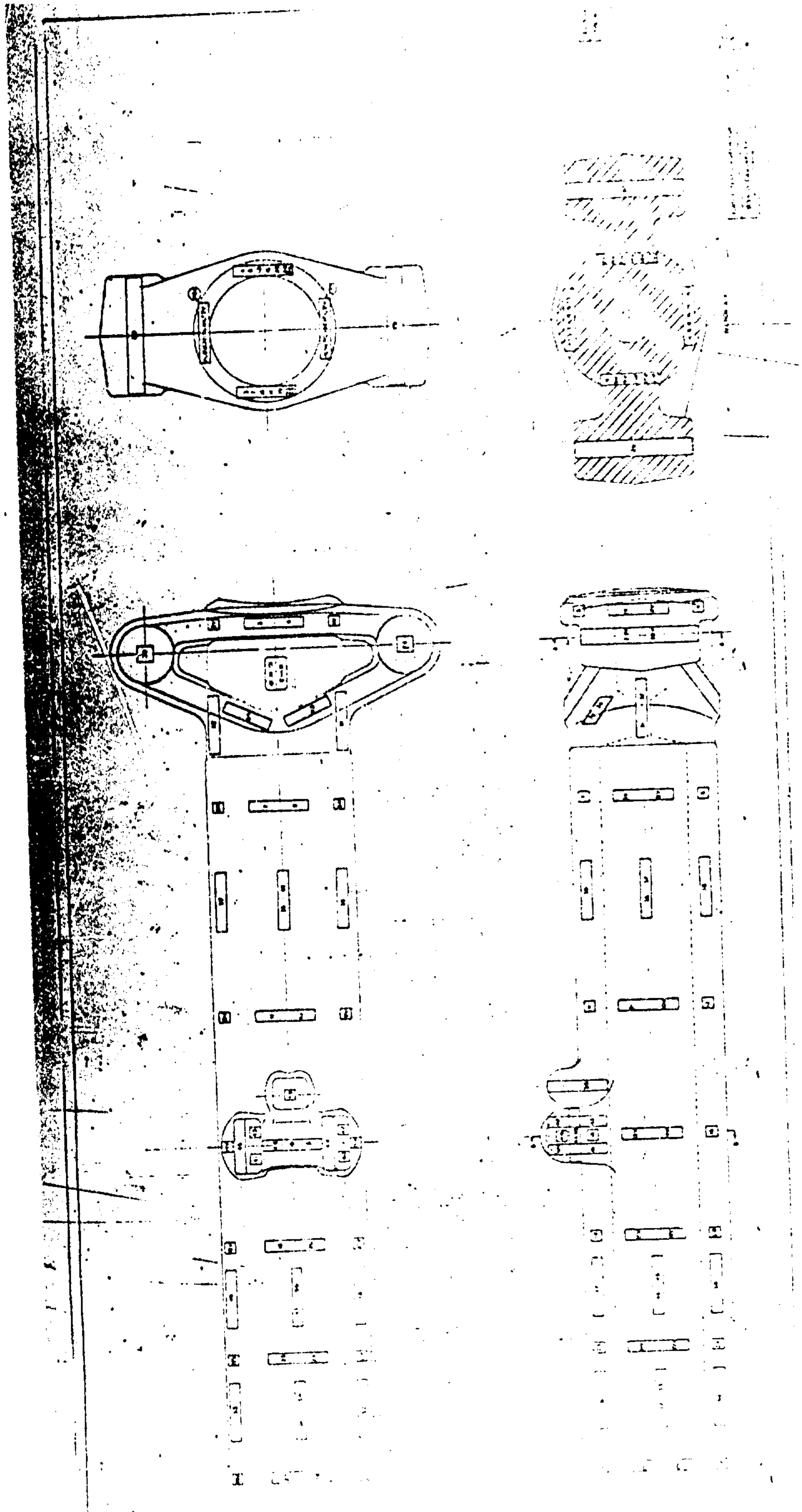


FIGURE 118 - Tensile Test Locations

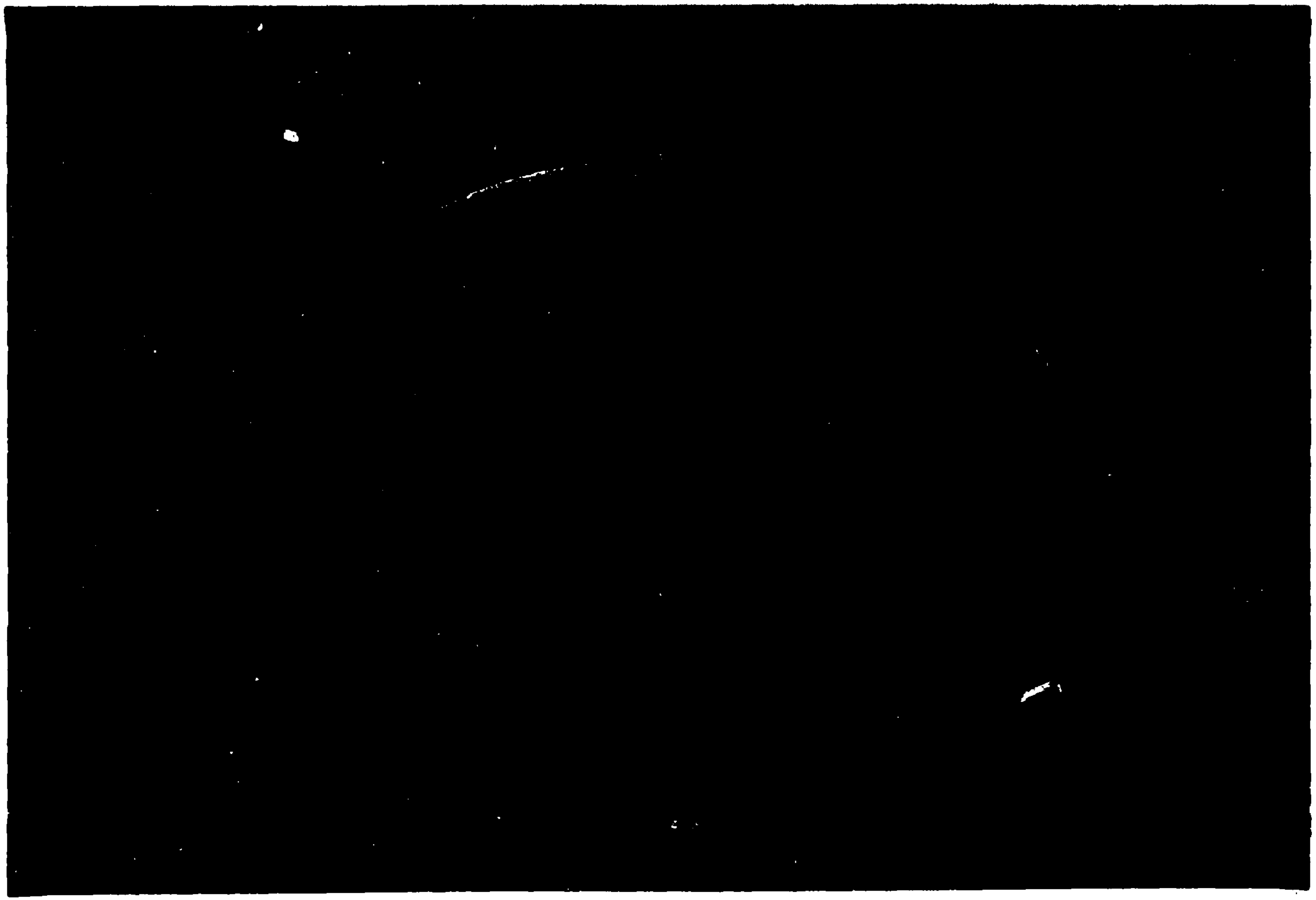


FIGURE 119 - Grain flow perpendicular to the bore axis, Location "A"
Etchant - 10% NaOH

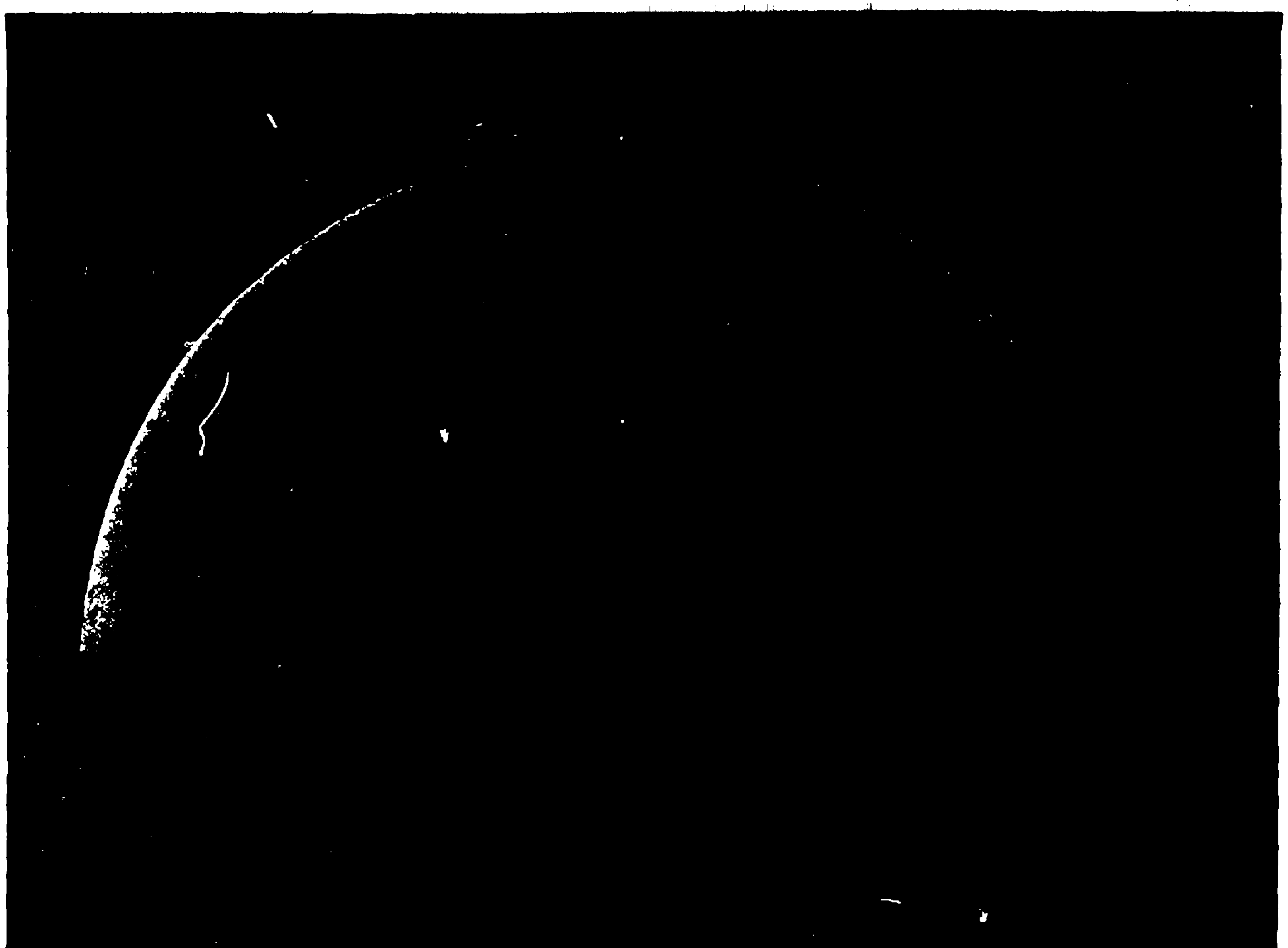


FIGURE 120 - Grain flow perpendicular to bore axis, Location "B" - Etchant 10% NaOH

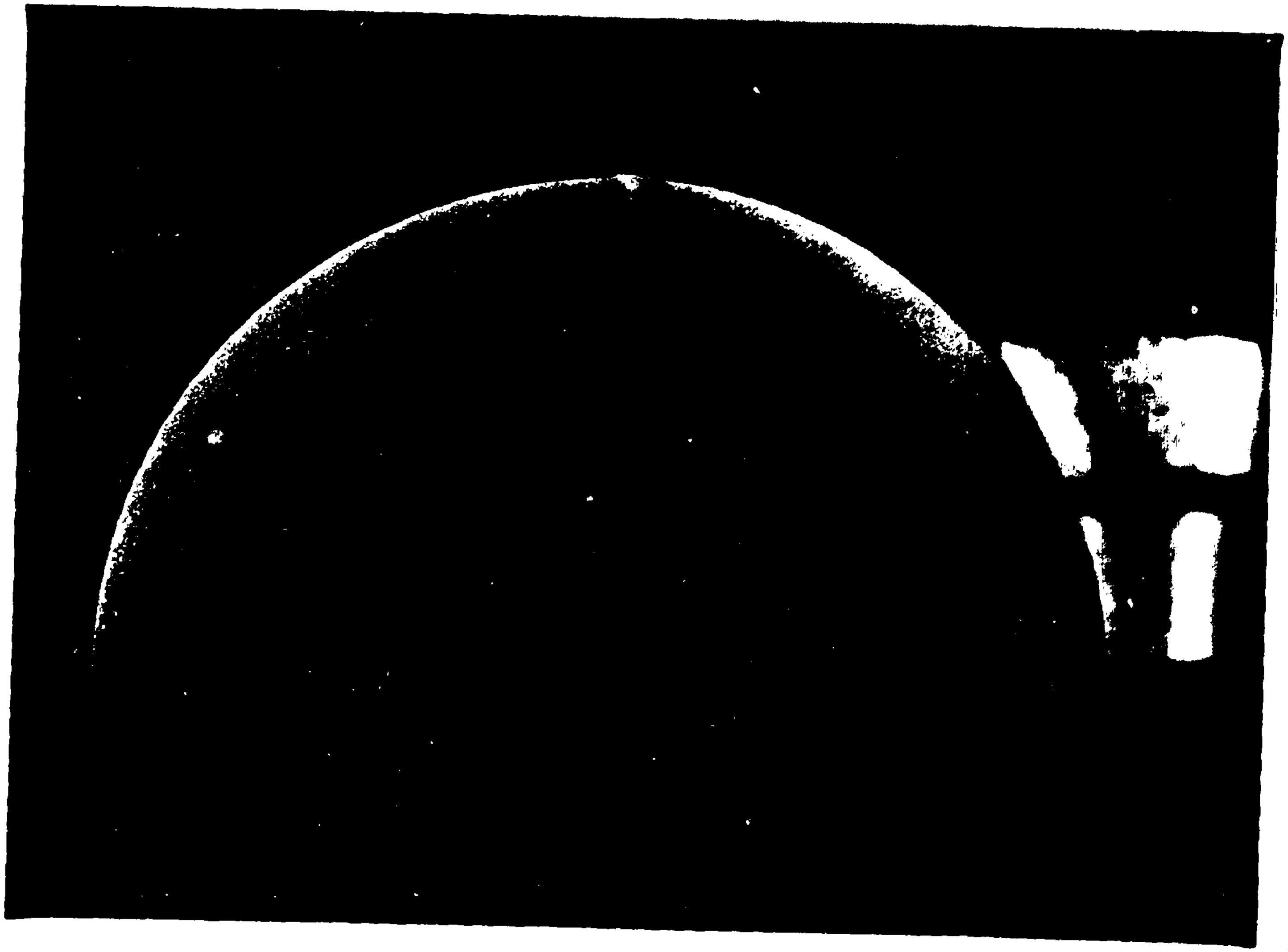


FIGURE 121 - Grain flow perpendicular to bore axis, Location 'C' - Etchant 10% NaOH

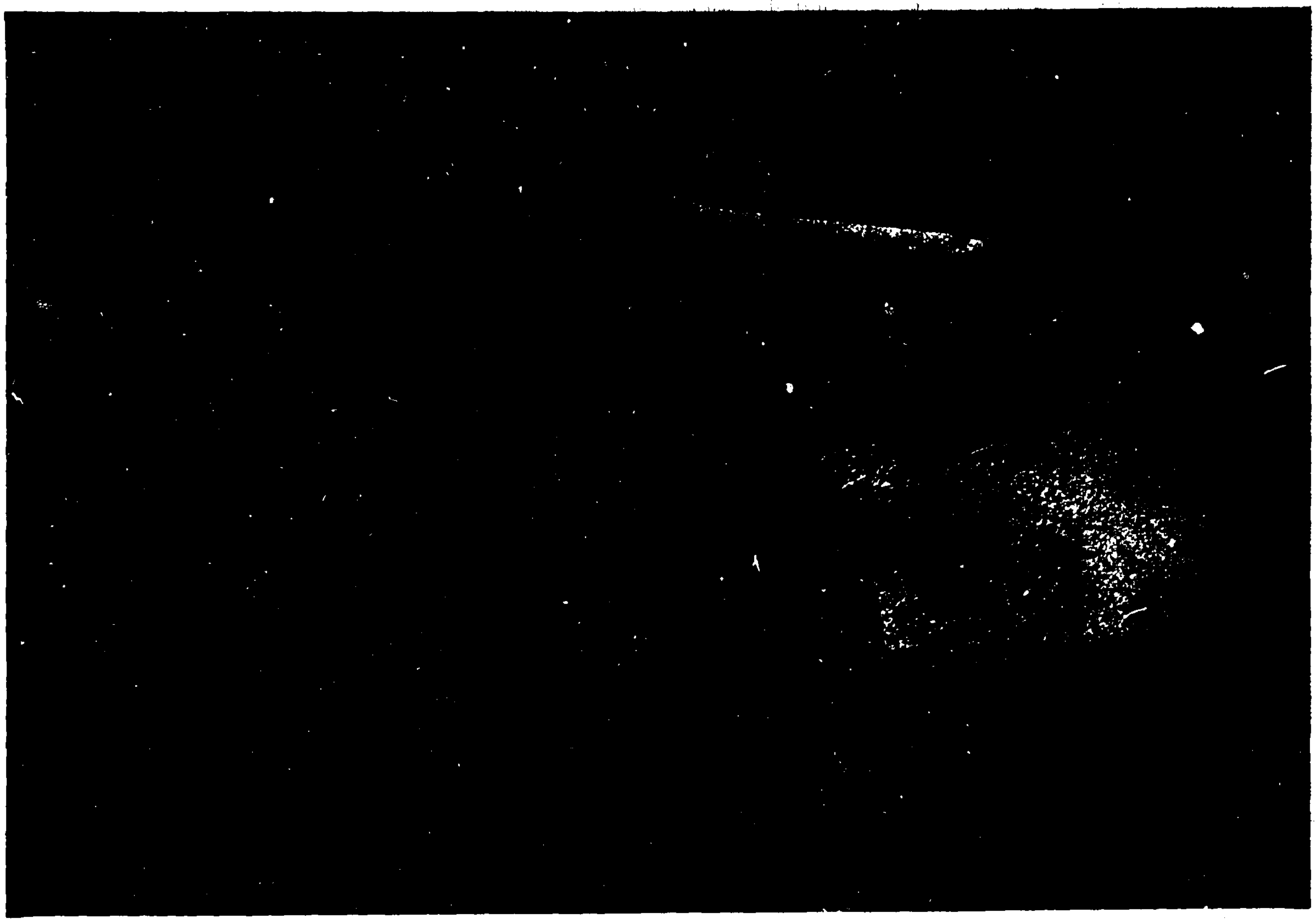


FIGURE 122 - Grain flow perpendicular to bore axis, Location "D" - Etchant 10% NaOH

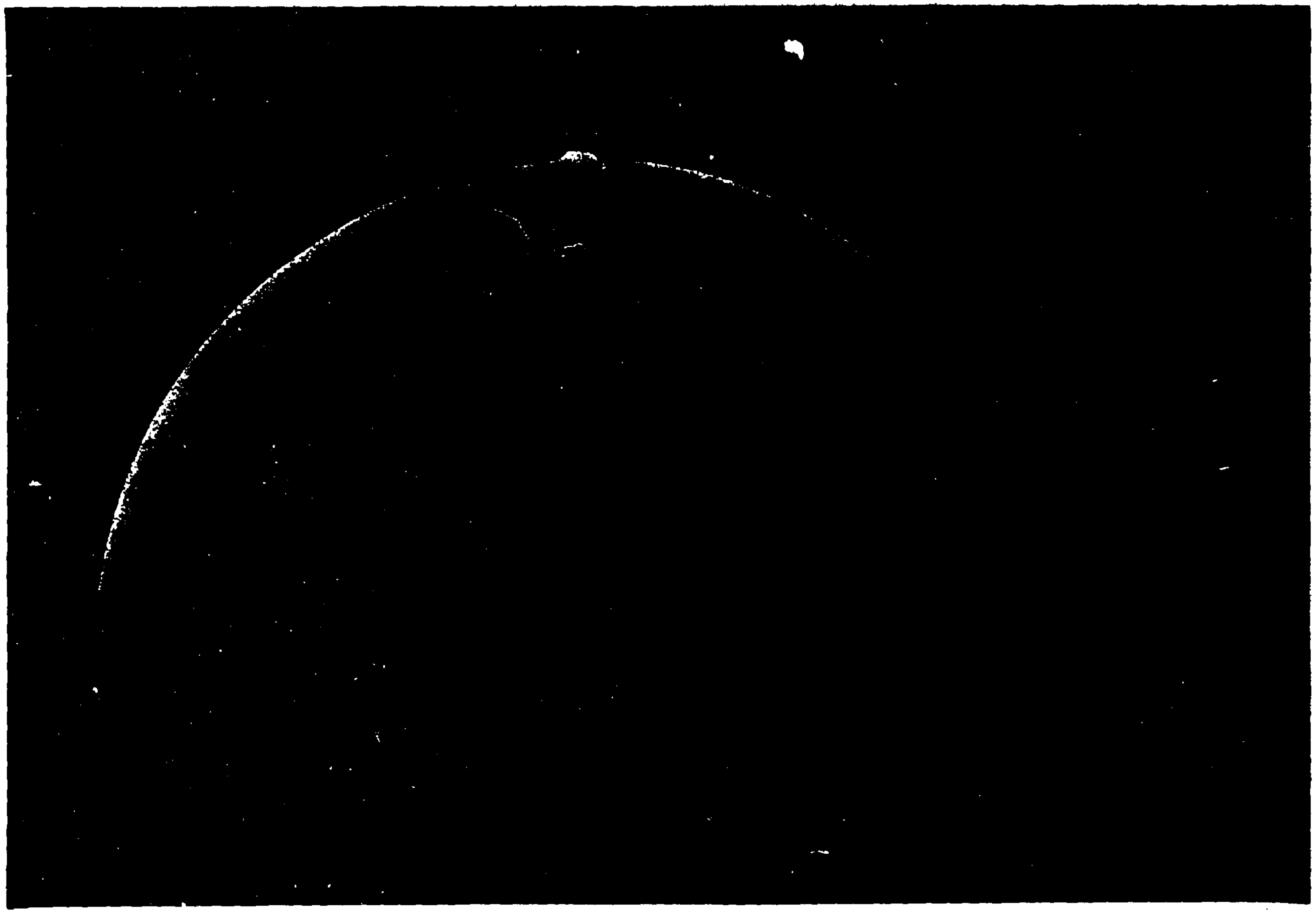


FIGURE 123 - Grain flow perpendicular to bore axis, Location "E" - Etchant 10% NaOH

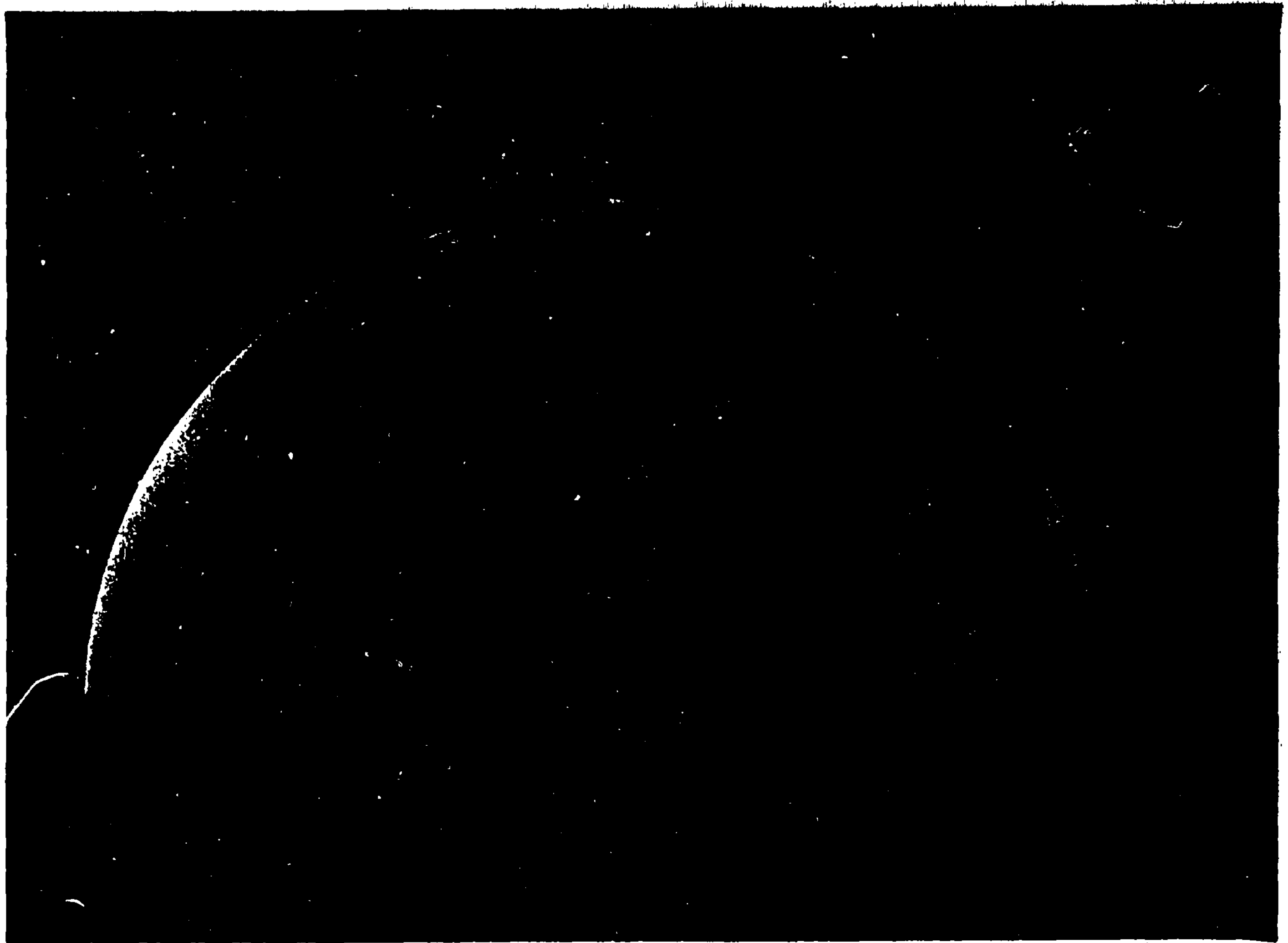


FIGURE 124 - Grain flow perpendicular to bore axis, Location "F" - Etchant 10% NaOH

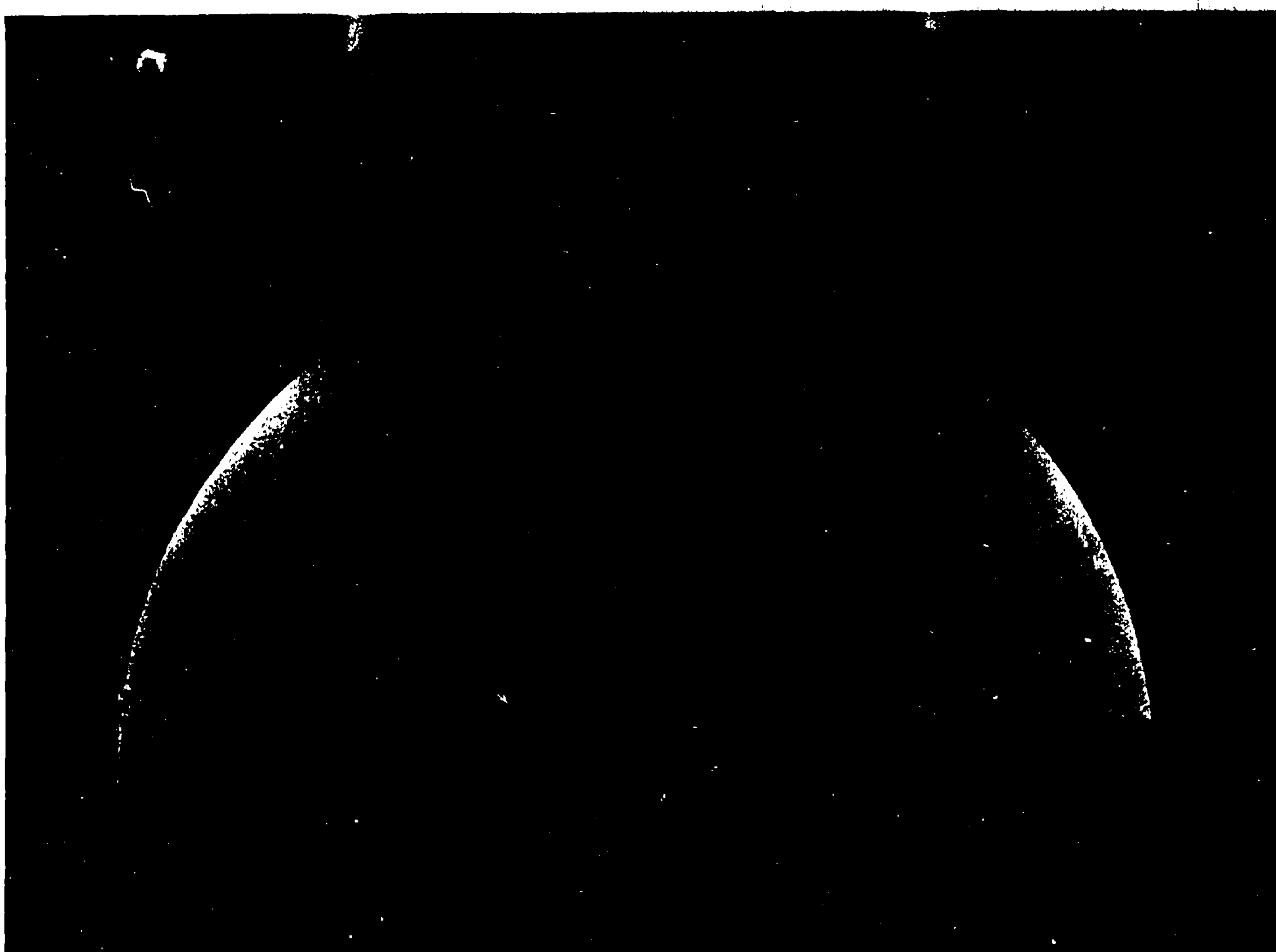


FIGURE 125 - Grain flow perpendicular to bore axis, Location "G" - Etchant 10% NaOH

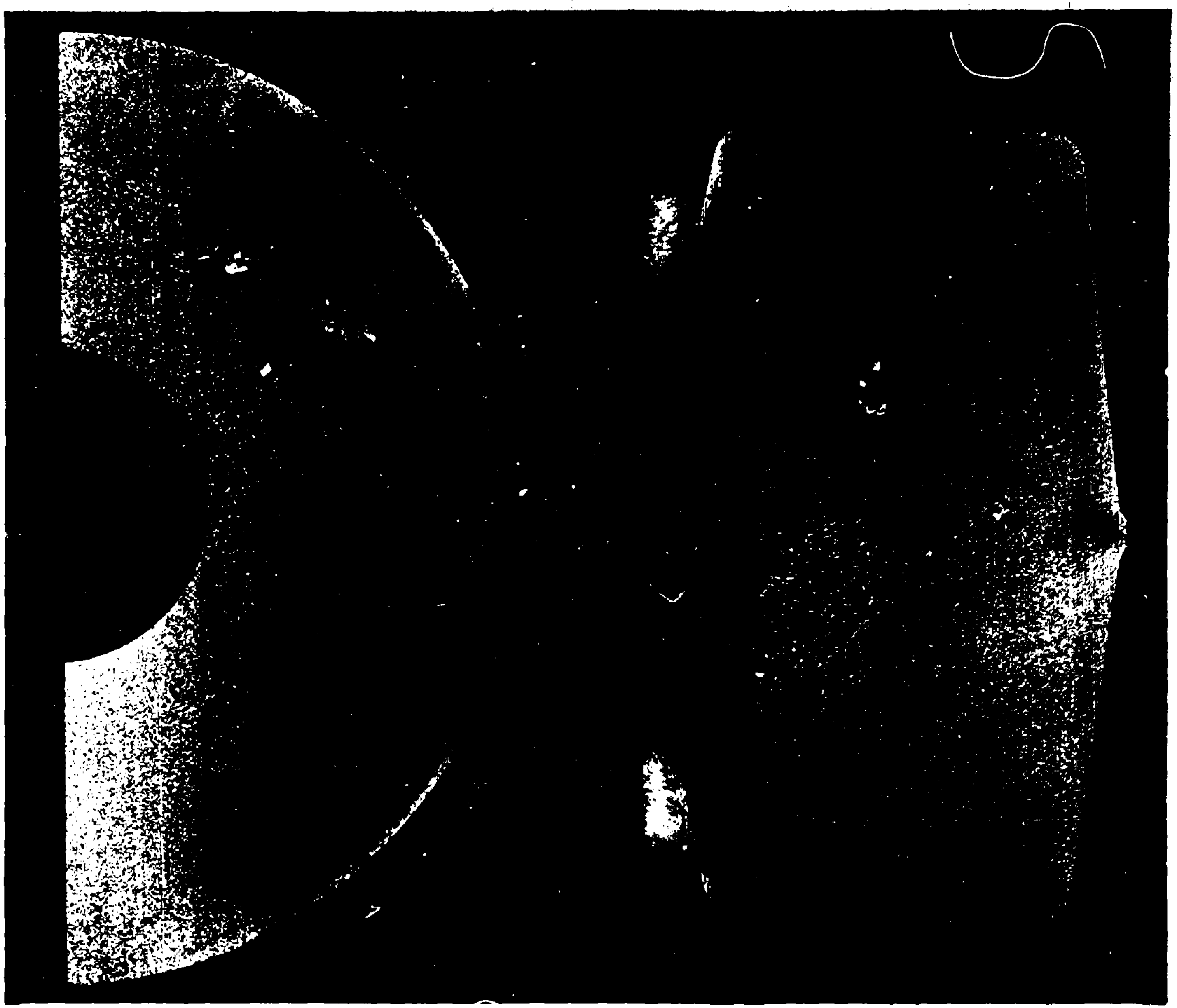


FIGURE 126 - Grain Flow perpendicular to bore axis, Location "H" - Etchant 10% NaOH

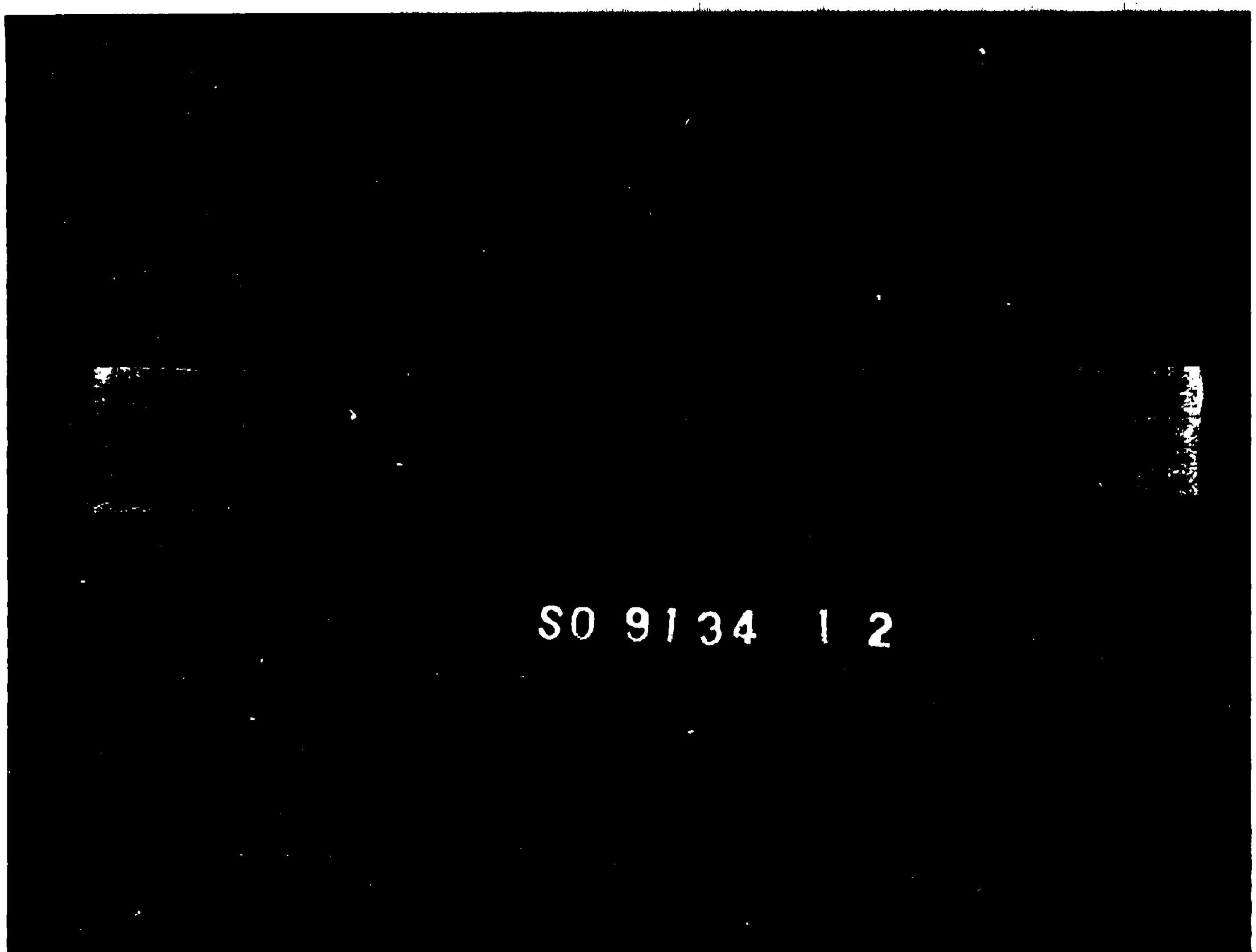


FIGURE 127 - Parting plane grain flow - Sections 1 & 2 - Etchant 10% NaOH

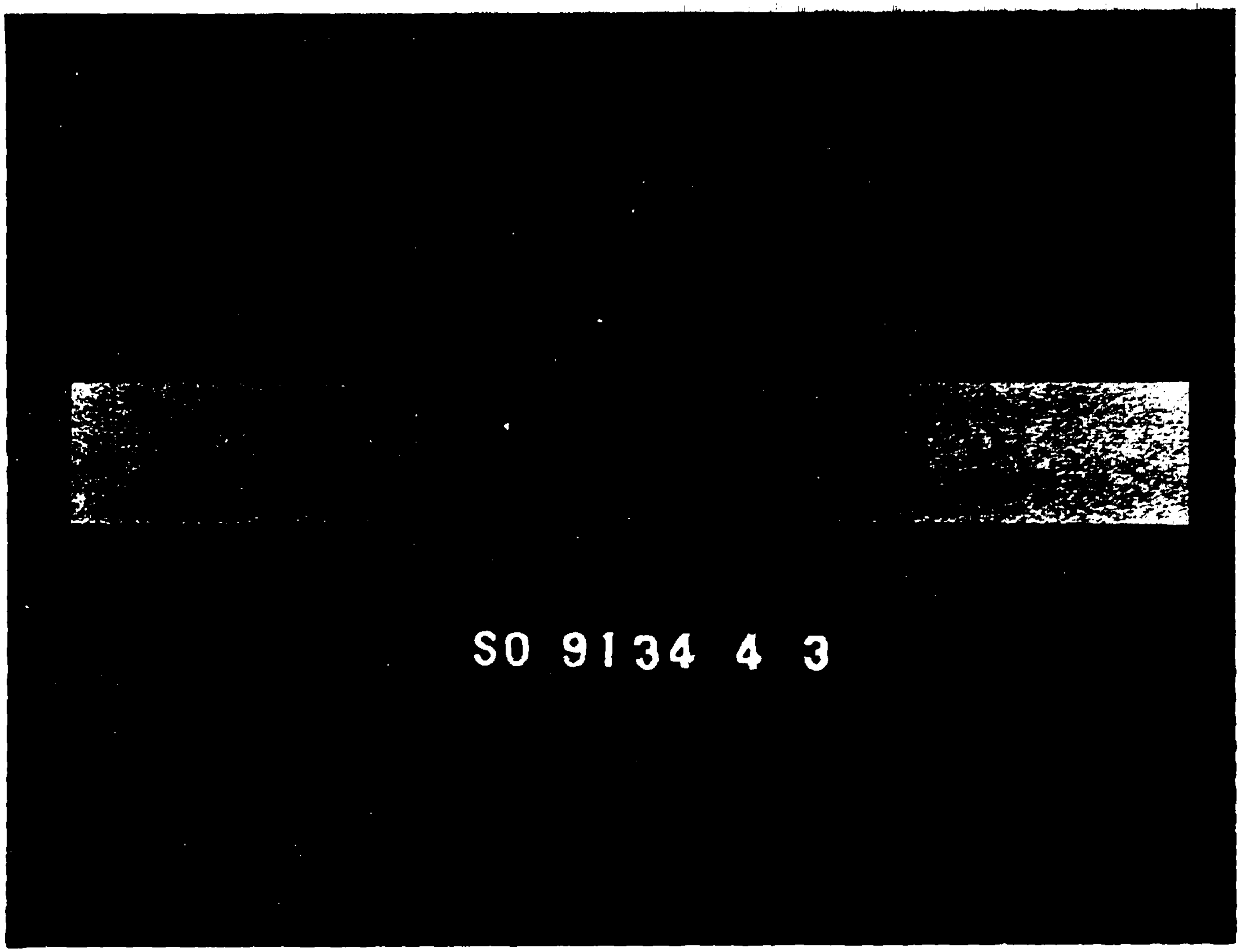


FIGURE 128 - Parting plane grain flow - Sections 3 & 4 - Etchant 10% NaOH

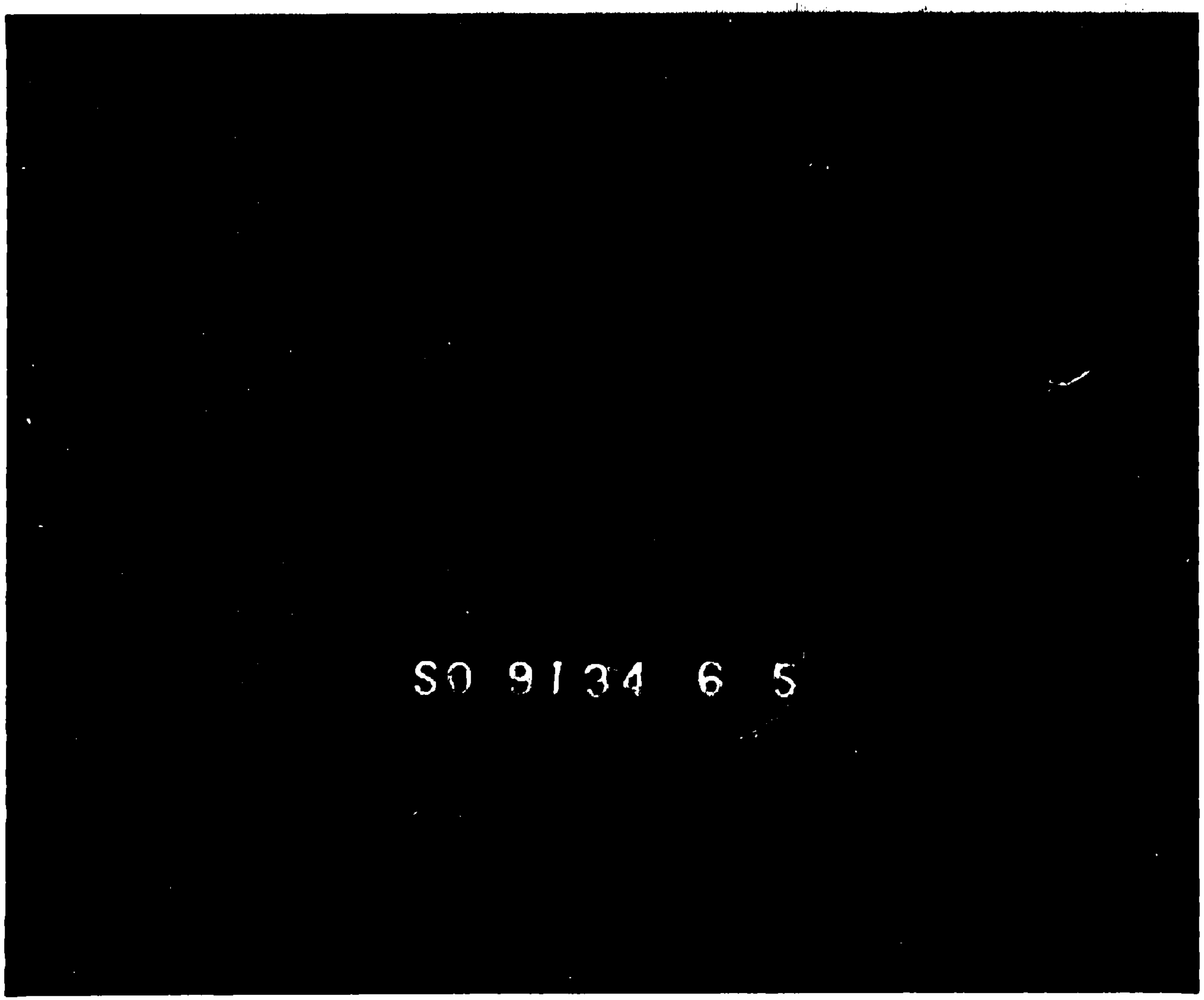


FIGURE 129 - Parting plane grain flow - Sections 5 & 6 - Etchant 10% NaOH

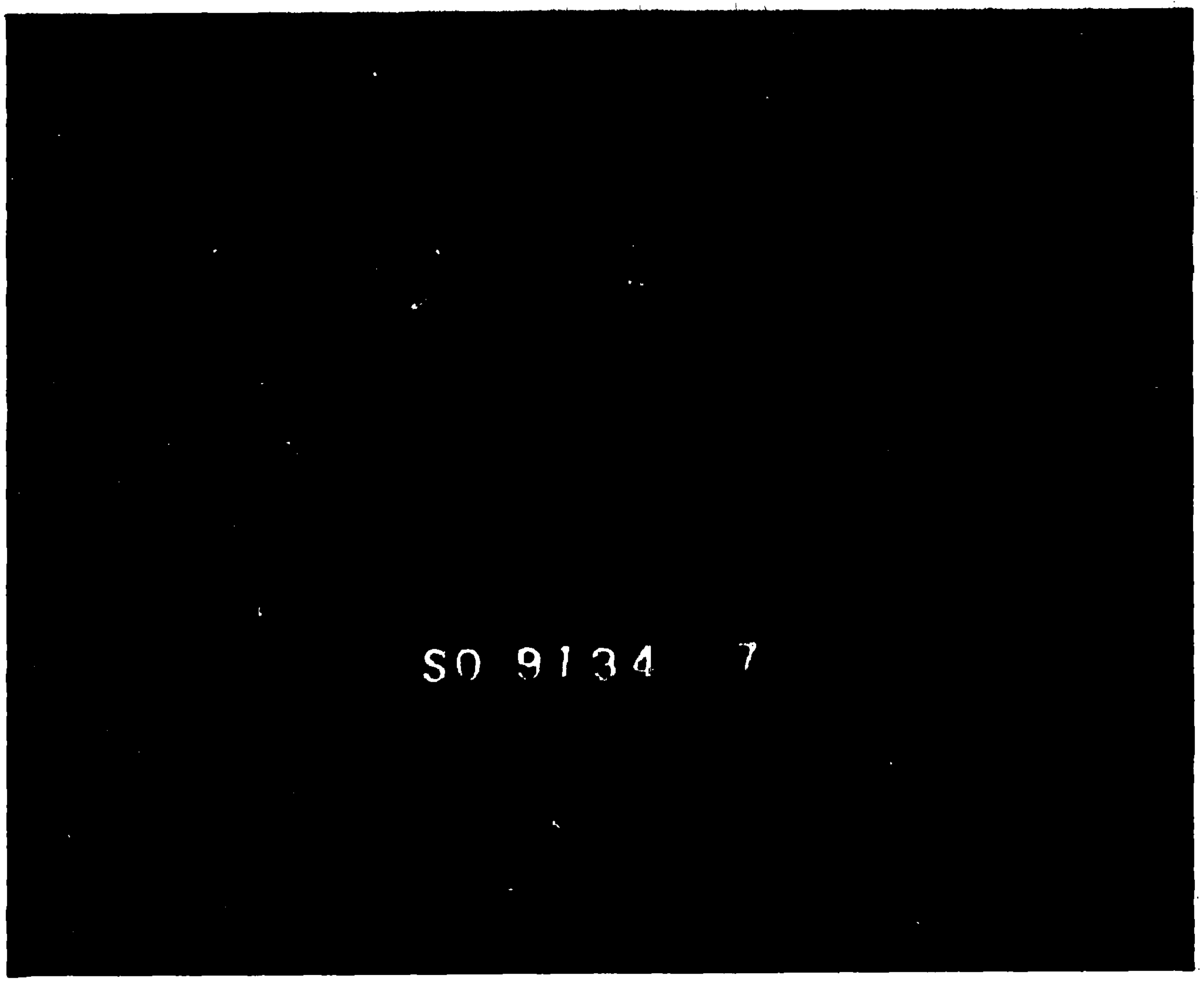


FIGURE 130 - Parting plane grain flow - Section 7 - Etchant 10% NaOH

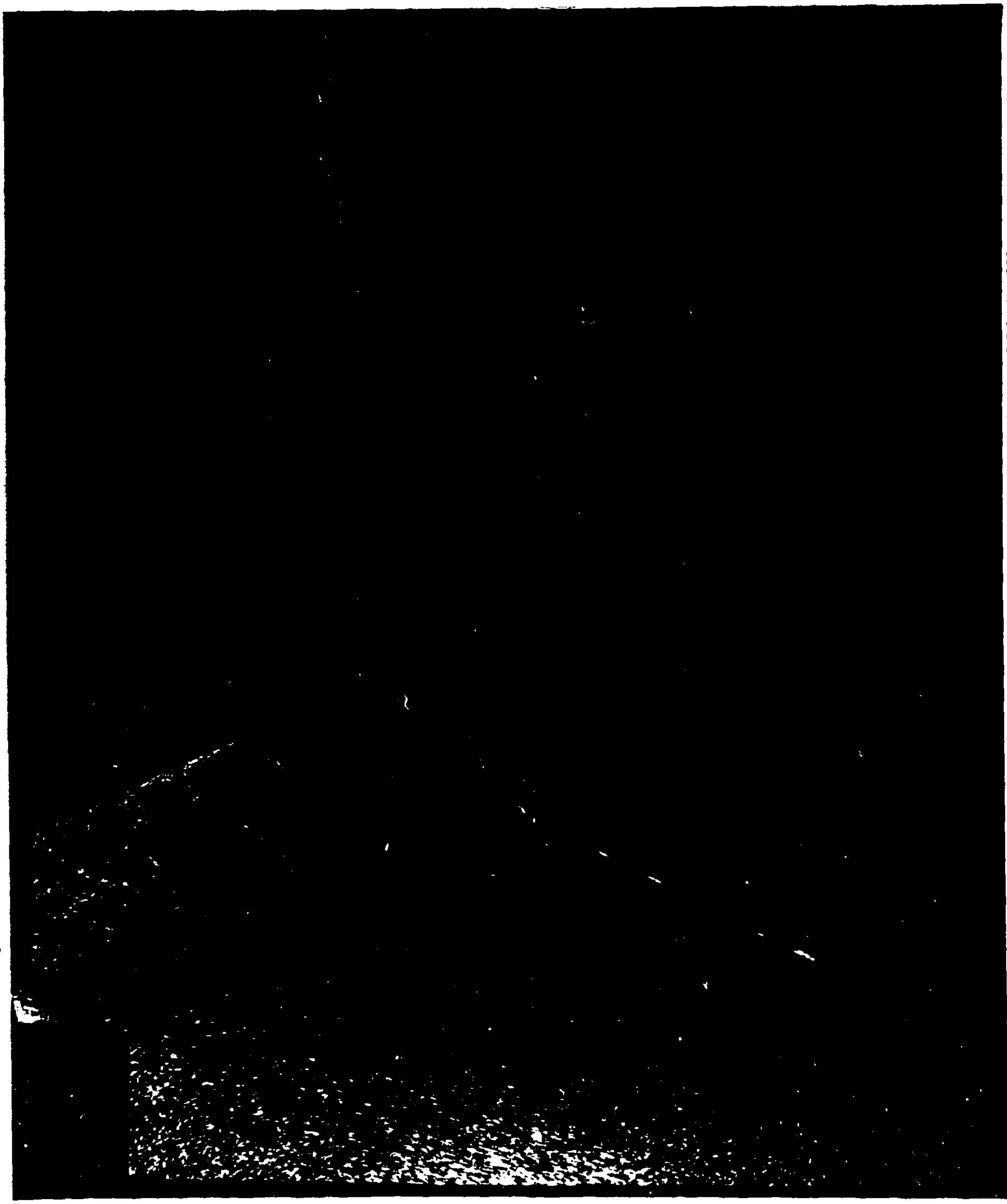


FIGURE 131 - Parting plane grain flow - Section 8 - Etchant 10% NaOH

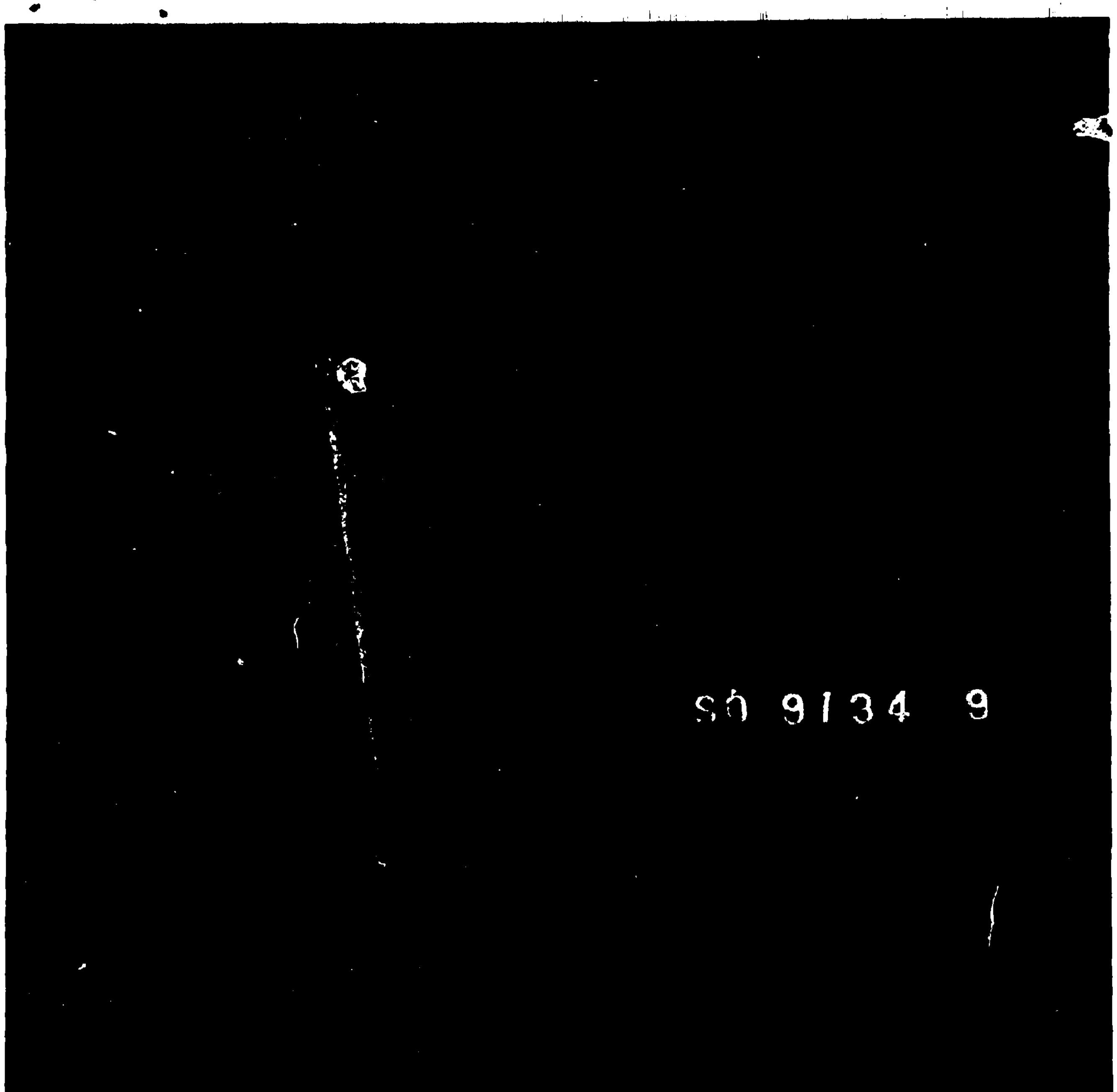


FIGURE 132 - Parting plane grain flow - Section 9 - Etchant 10% NaOH

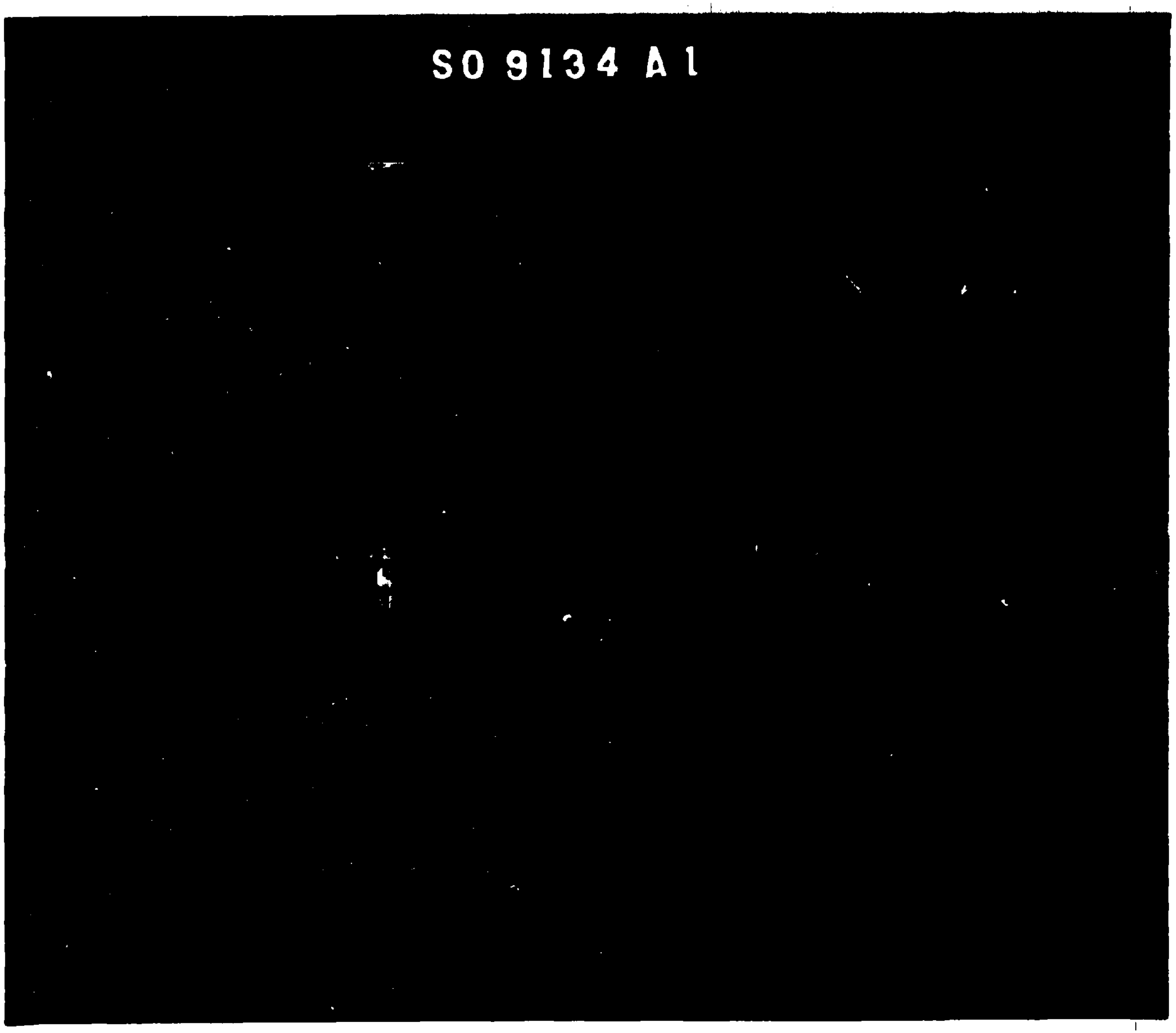


FIGURE 133 - Grain flow 90°to the parting plane - Section 1 - Etchant 10% NaOH

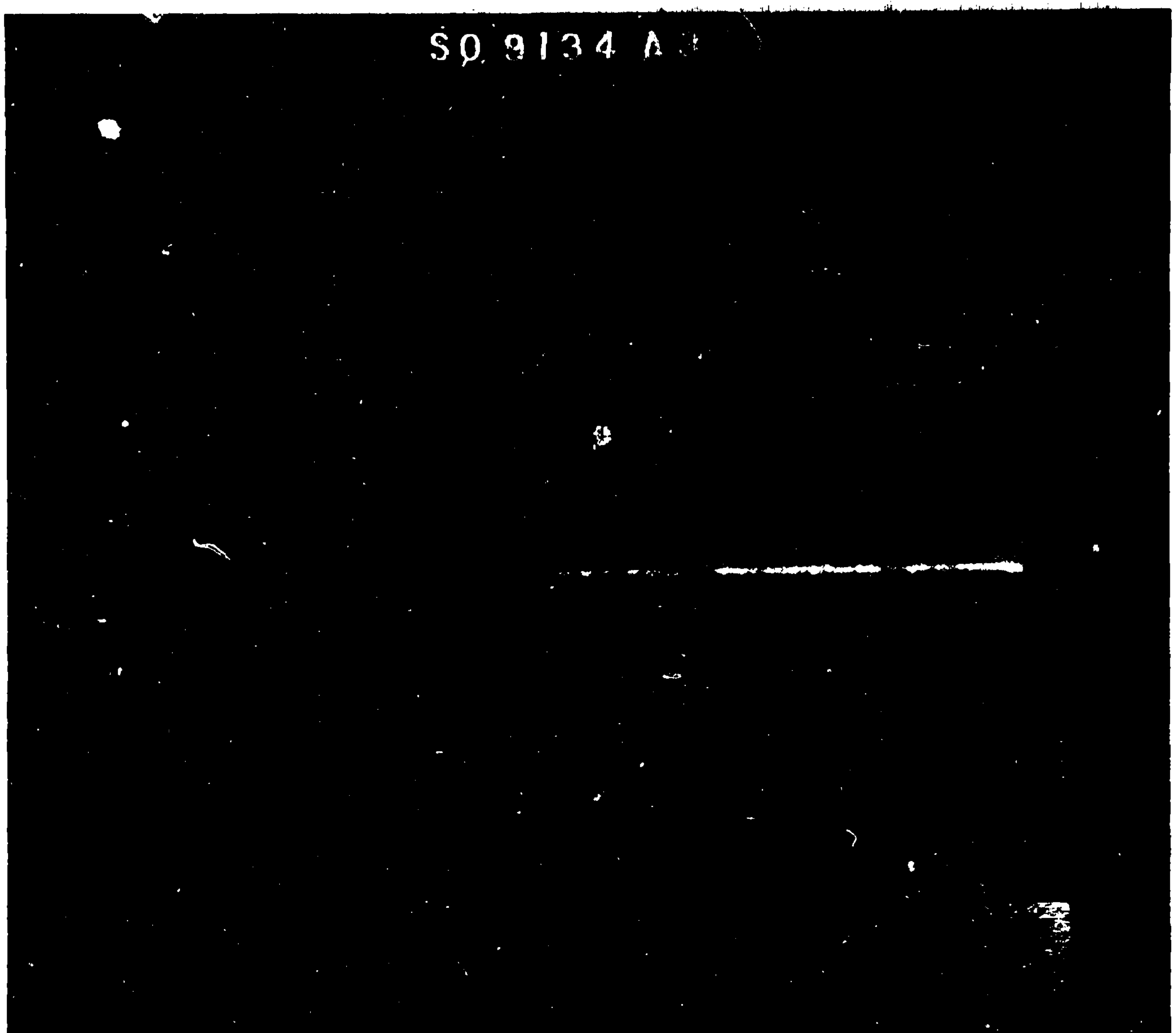


FIGURE 134 - Grain flow 90°to the parting plane - Sections 2 & 3 - Etchant 10% NaOH

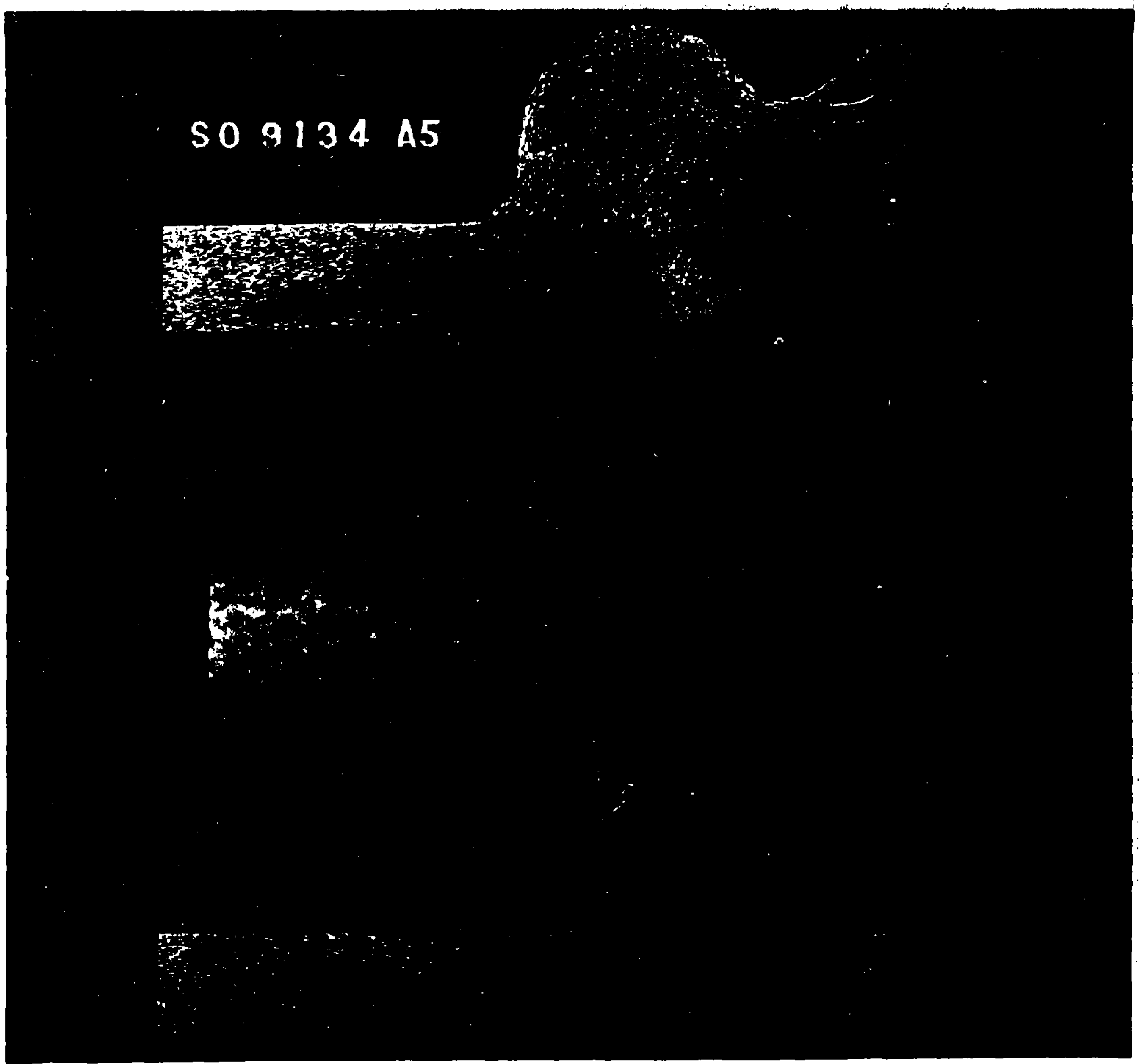


FIGURE 135 - Grain flow 90° to the parting plane - Sections 4 & 5 - Etchant 10% NaOH

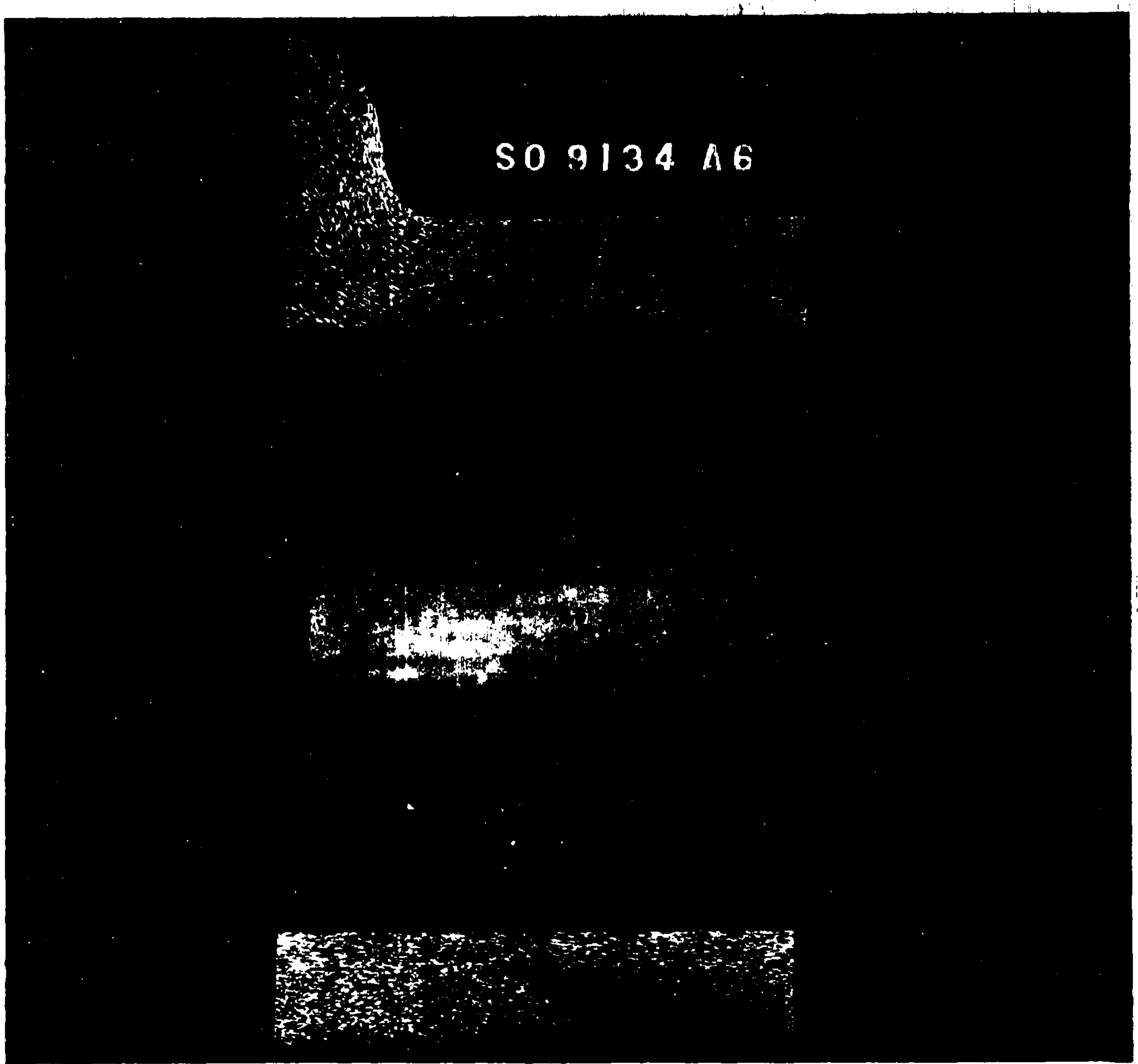


FIGURE 136 - Grain flow 90°to the parting plane - Section 6 - Etchant 10% NaOH

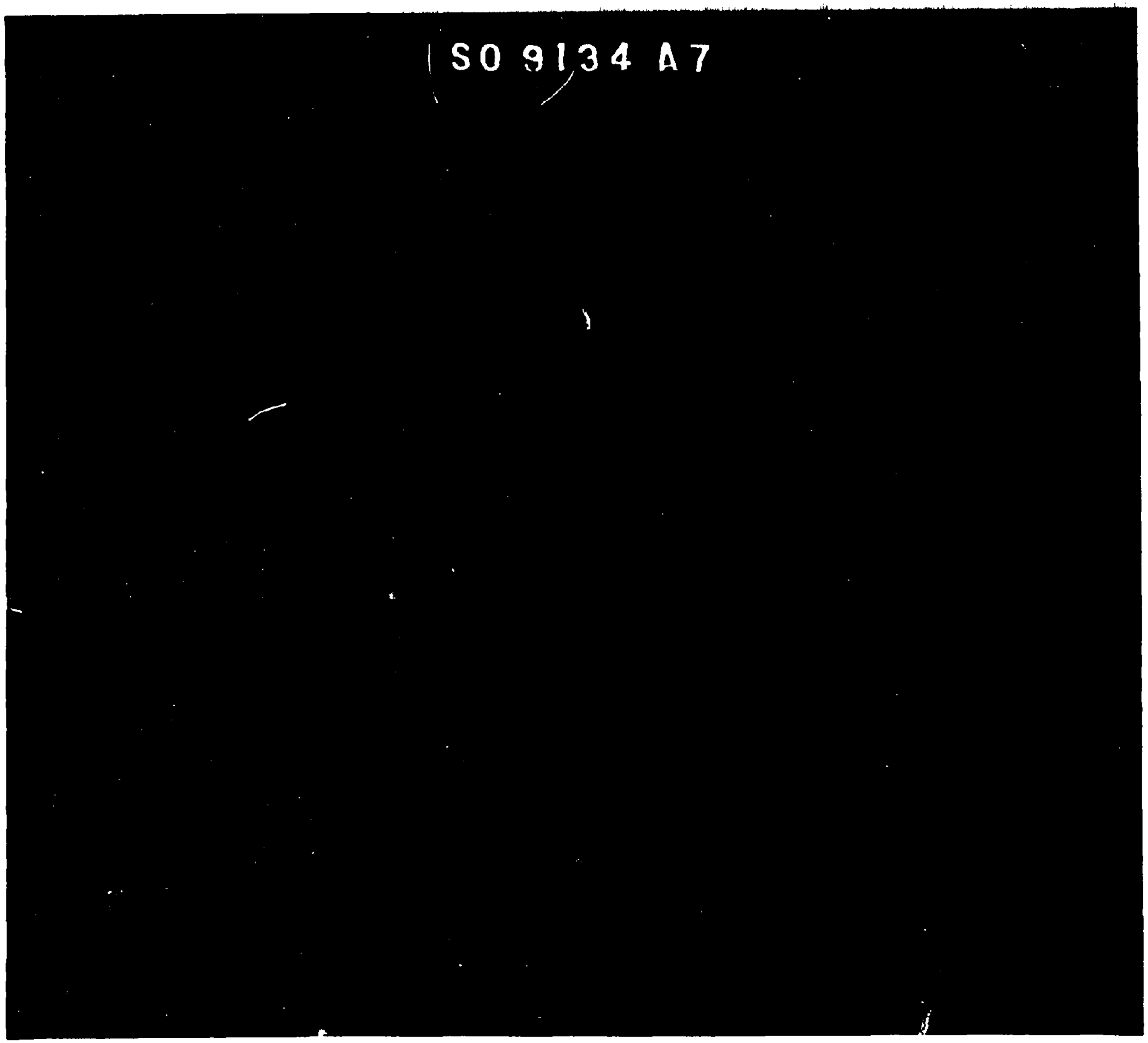


FIGURE 137 - Grain flow 90^{o} to the parting plane - Section 7 - Etchant 10% NaOH

FIGURE 138 - Grain flow 90°to the parting plane - Section 8 - Etchant 10% NaOH

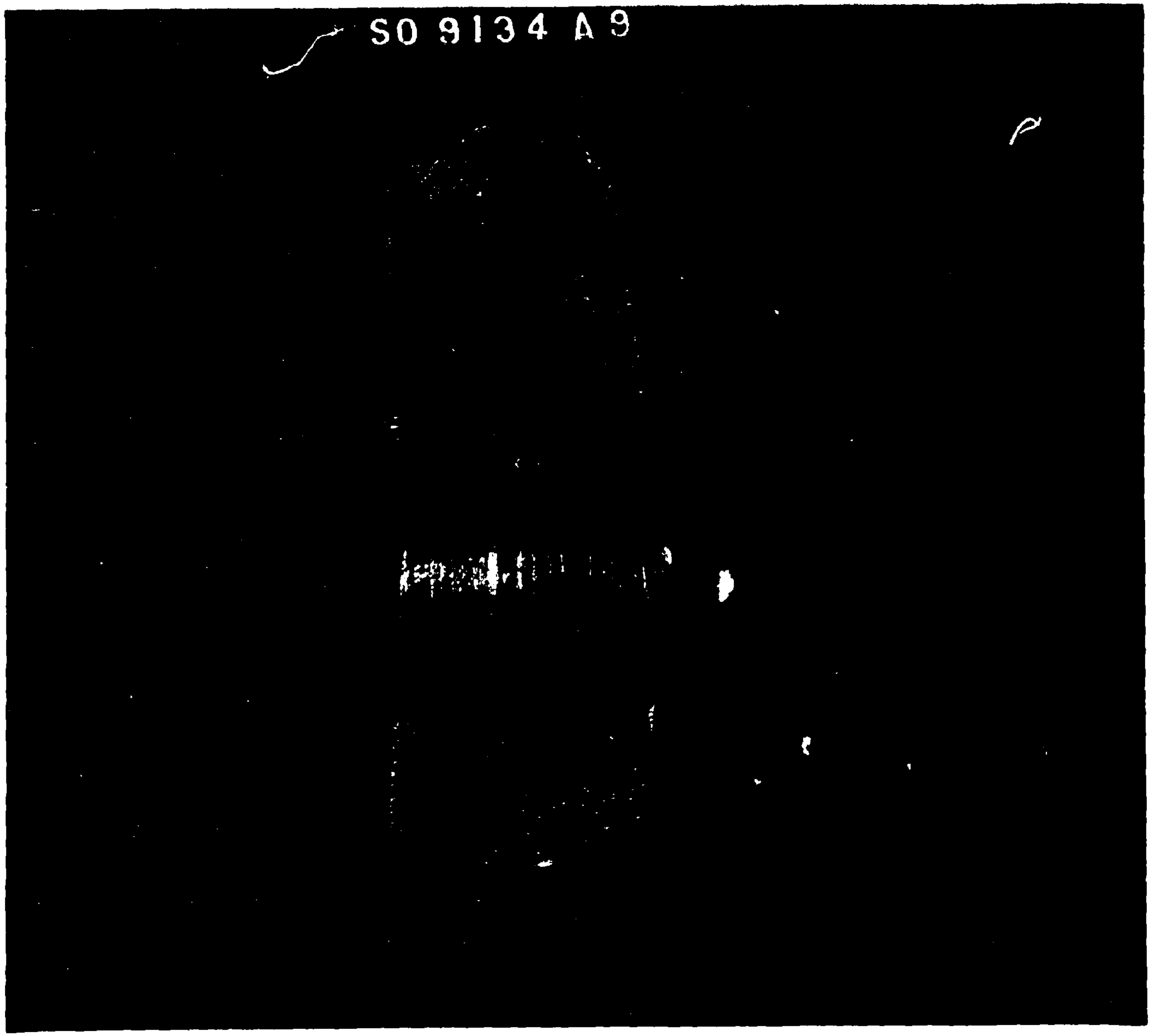


FIGURE 139 - Grain flow 90°to the parting plane - Section 9 - Etchant 10% NaOH

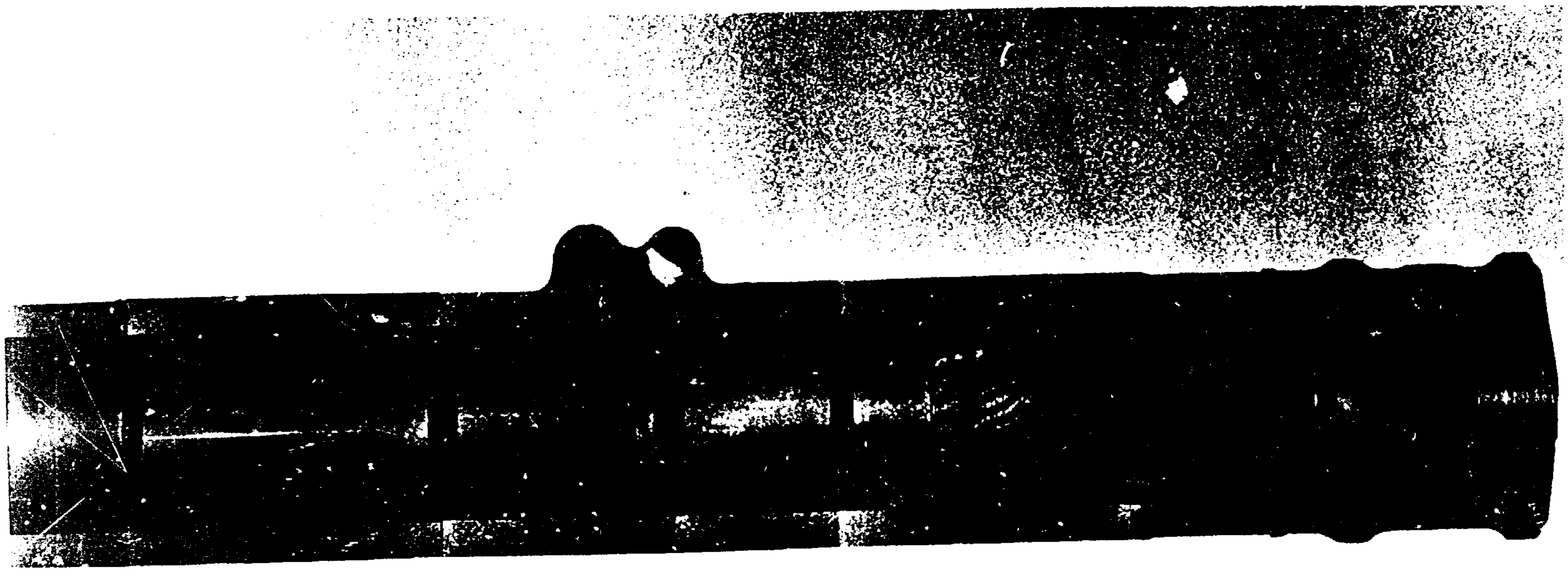


FIGURE 140 - Composite grain flow of sections cut 90° to the parting plane

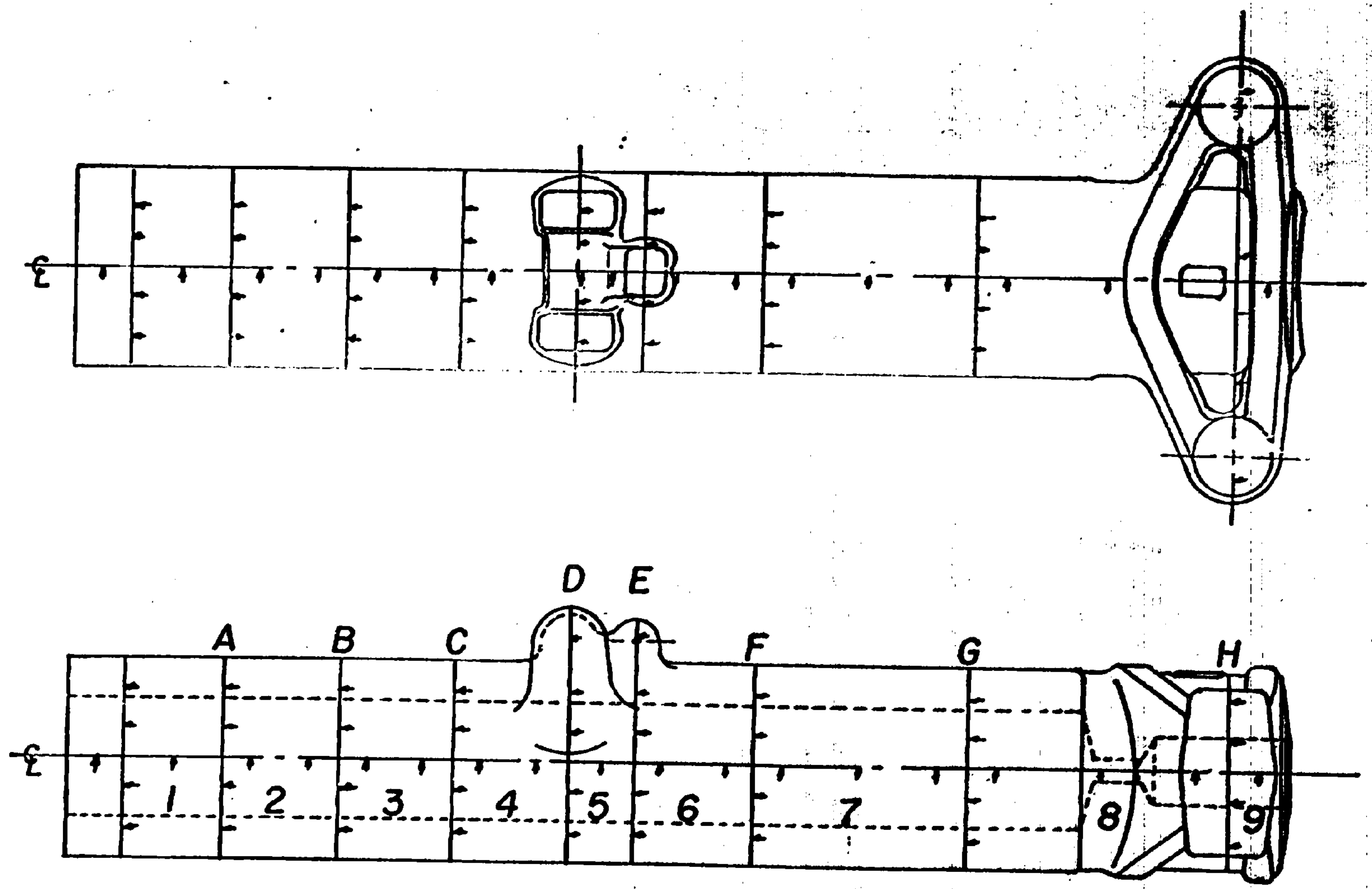


FIGURE 141 - Method of sectioning and location of grain flows

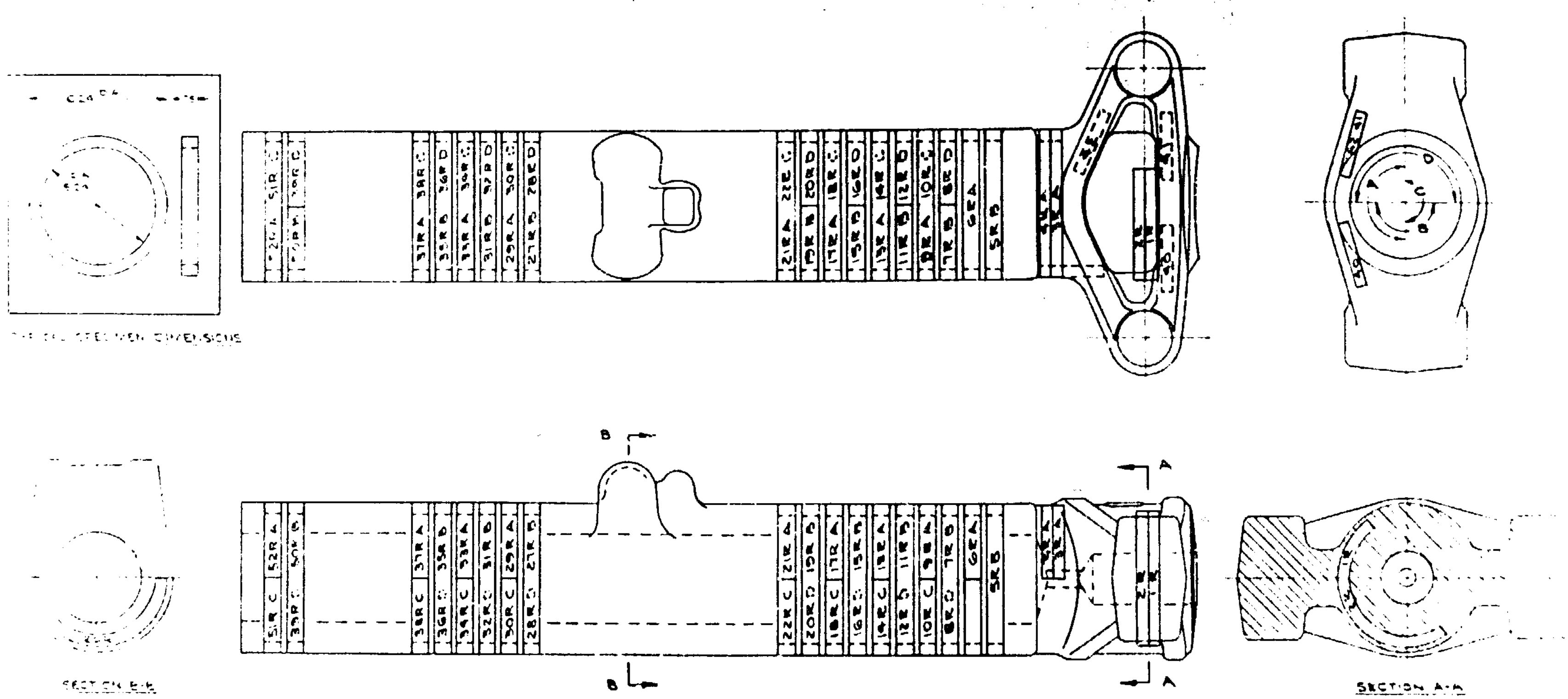


FIGURE 142 - Stress corrosion test locations

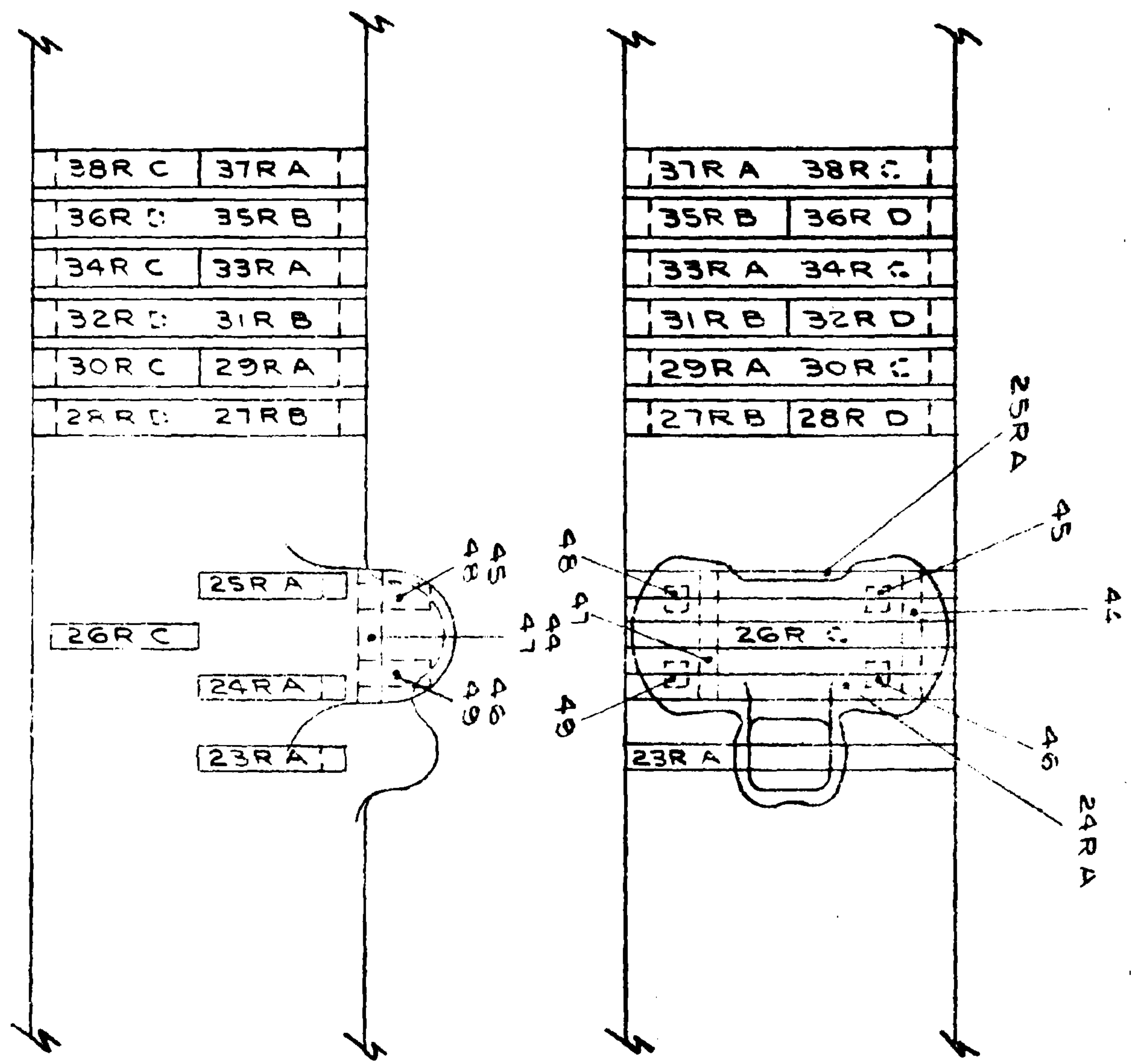
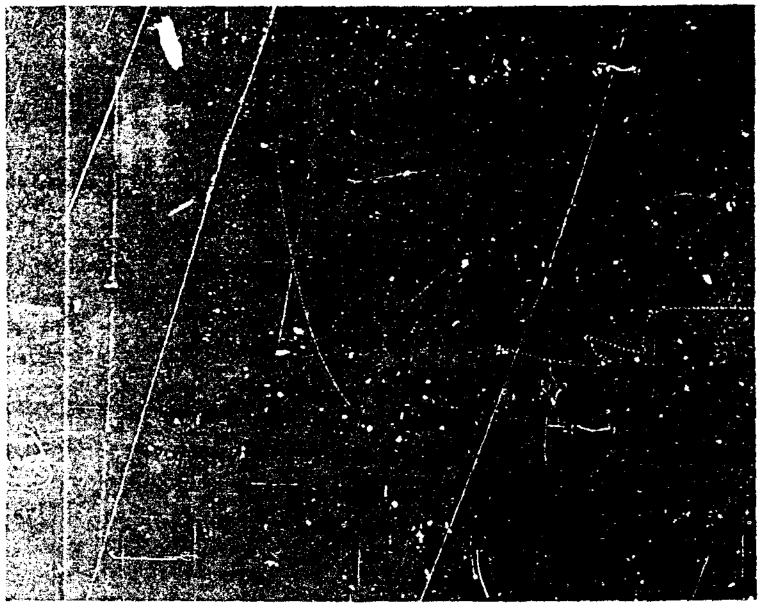
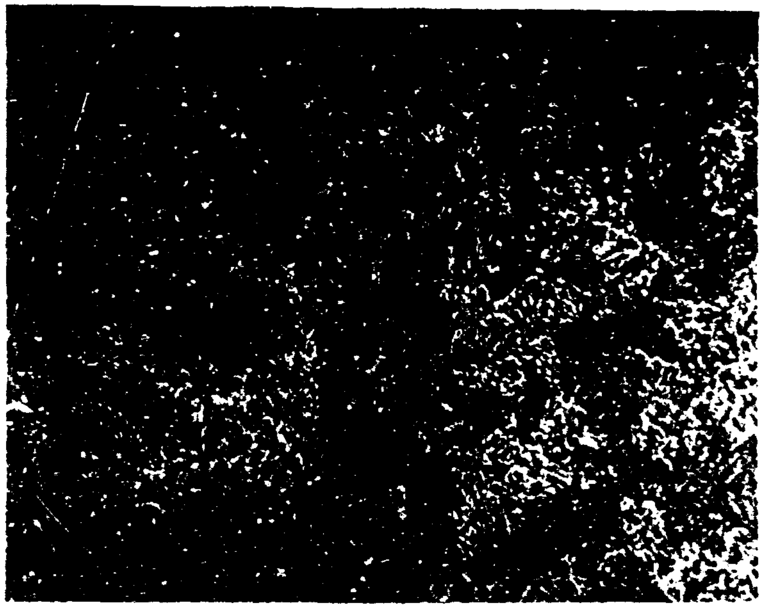


FIGURE 142A - Stress corrosion test locations

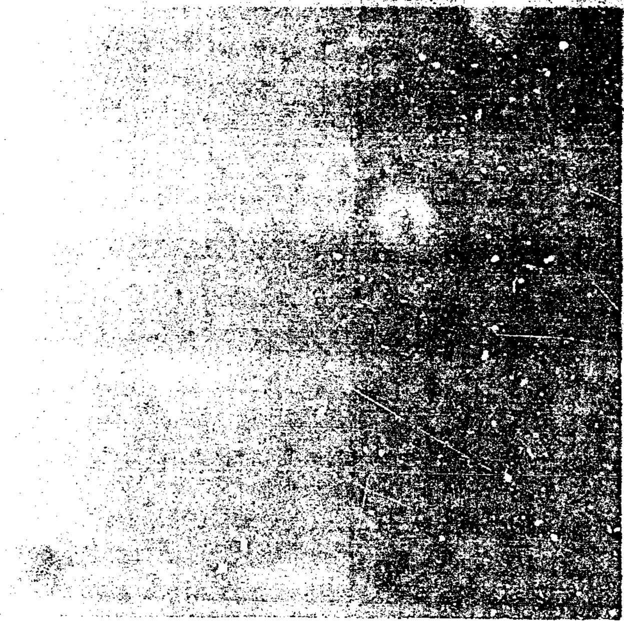


Polished on a tangential plane parallel to the bore axis adjacent to the bore surface.
X100 Etchant Mod. Keller's



Polished on a plane perpendicular to the bore axis.
X100 Etchant Mod. Keller's

Figure 143. Stress corrosion test ring 3R from forging S/N 24. The ring I.D. was stressed at 30,000 PSI. Test failed in 33 Days.



...ngential plane parallel
... adjacent to the bore

... Mod. Keller's

Polished on a plane perpendicular
to the bore axis.
X100 Etchant Mod. Keller's

... test ring 2AR from forging S/N30. The ring I.D. was stressed
... ksi. Test failed in 44 Days.

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13. ABSTRACT

To evaluate SCC susceptibility as it relates to forging processing, a 7079 aluminum alloy landing gear outer cylinder was produced using five different forging techniques. Three of these techniques formed the part with a solid barrel using differing preliminary open die working. The other two techniques involved forward and backward extrusion.

Standard uniaxial-tensile testing revealed no significant difference between the various forging techniques. However, alternate immersion stress corrosion testing in 3½% NaCl indicated differences in stress corrosion cracking susceptibility. The two extruded forgings (forward and back) were significantly more resistant to SCC. The forward extruded parts were somewhat more resistant to SCC than the back extruded parts, but were also substantially more expensive to produce.

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